National Aeronautics and Space Administration

Flight Deck Surface Trajectory-based Operations (STBO): Results of Piloted Simulations and Implications for Concepts of Operation (ConOps)

David C. Foyle, NASA Ames Research Center
Becky L. Hooey and Deborah L. Bakowski, San Jose State University

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NextGen Flight Deck Taxi Clearance Compliance

Problem

1. Current-day flight deck operations are not able to support:
- NextGen Arrival - Anticipated throughput generated by NextGen concepts such as M&S, VCSPA, etc.
- NextGen Departure - Predictability required for NextGen concepts.

(re: IADS RTT ConOps 4-12-10)

2. Must work ATC concepts in parallel with flight deck concepts or be vulnerable to risk of developing concepts to which pilots cannot comply.

(i.e., IADS RTT Doc: "OV-6c NEXTGEN 2018 Scenario 07 - Peak Departures v0.1 4-13-2009")

Research Needs

- Develop/assess Surface Traffic Mgmt. Systems / Flight Deck ConOps variants
- Determine technologies/procedures for pilots to conduct NextGen taxi operations
- Assess compliance and pilot workload under NextGen IADS operations
- Define and conduct RTT IADS RTP efforts

Approach

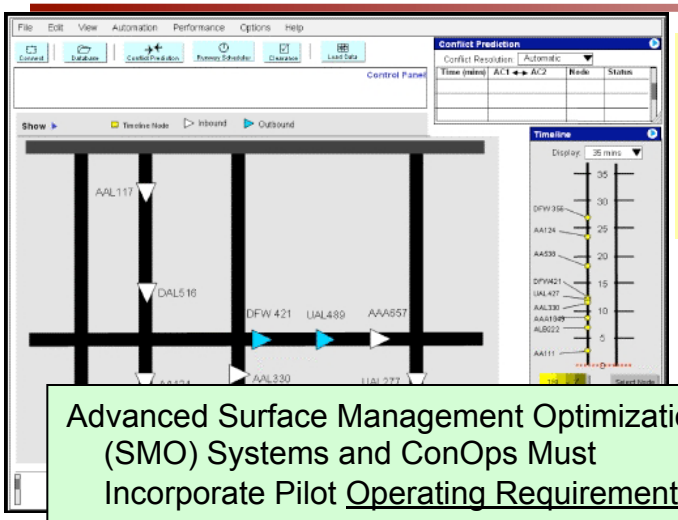
Iterative Pilot-in-the-loop Simulations
- ConOps Definition / refinement
- Pilot compliance
- Pilot info. requirements
- Pilot acceptance

Impact
- ConOps Development
- SMS Algorithm/Parameters Development
- Flight Deck System Requirements
- Robust systems (e.g., off-nominals)

Progress

- Multiple simulations
- Defined ConOps options
- Eliminated specific candidate ConOps options

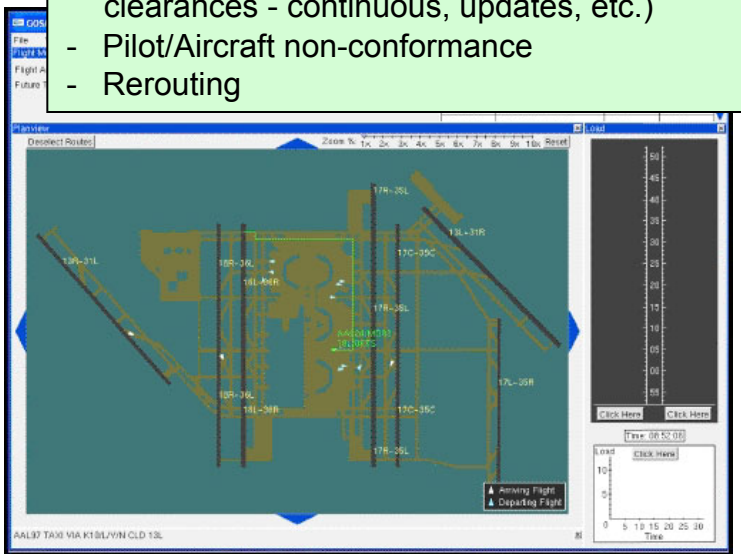
Pilot requirements for Surface Trajectory Based Operations (STBO) clearances



Problem: Integrating Surface Management Optimization (SMO) STBO clearances with flight deck information requirements

Advanced Surface Management Optimization (SMO) Systems and ConOps Must Incorporate Pilot Operating Requirements

- Ability to comply with speed requests
- Variance of route and time conformance
- Conceptual development (e.g., form of taxi clearances - continuous, updates, etc.)
- Pilot/Aircraft non-conformance
- Rerouting



Human Factors Pilot-in-the-loop Studies to Determine Pilot Operating Requirements

- Speed conformance
- Route and time conformance
- Conceptual (ConOps) development
- Pilot workload, Situation awareness (SA)
- Safety impacts due to time pressure

STBO Flight Deck Issues

STBO Concepts
- Progressive taxi/route updates
- Continuous-coupled STBO clearances
- Endpoint-only STBO Clearances (push-back, departure queue)

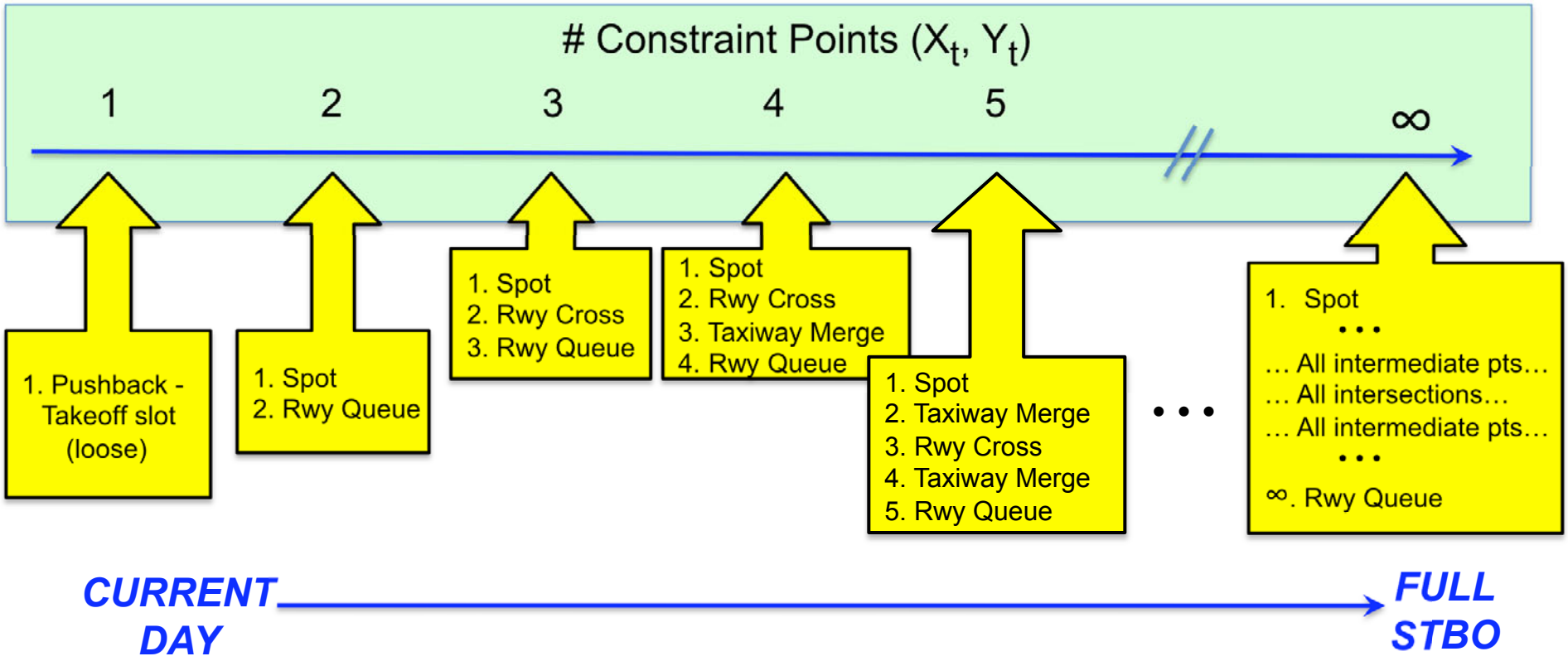
STBO Taxi Clearance Formats
- Flight Deck speed & time displays
- Bandwidth of error-nulling (i.e., continuous vs. non-continuous checkpoint error)
- ATC STBO Clearance: Speed, Time

Pilot Performance Metrics
- Variance of speed, time-of-arrival error
- SA, workload, safety impacts

NextGen Taxi / Surface Trajectory-Based Operations (STBO)

Surface Trajectory-Based Operations (STBO) inherently different than In-Air TBO

- In-Air: More constrained – due to aircraft inertia, min/max speeds, in-trail separations.
  → More predictable, much more likely to have fully defined trajectories: X(t), Y(t)
- Taxi: Not constrained – aircraft start, stop, wait, merge into queues, no min. separation
  → Less predictable, more variants on defining STBO than in-air TBO



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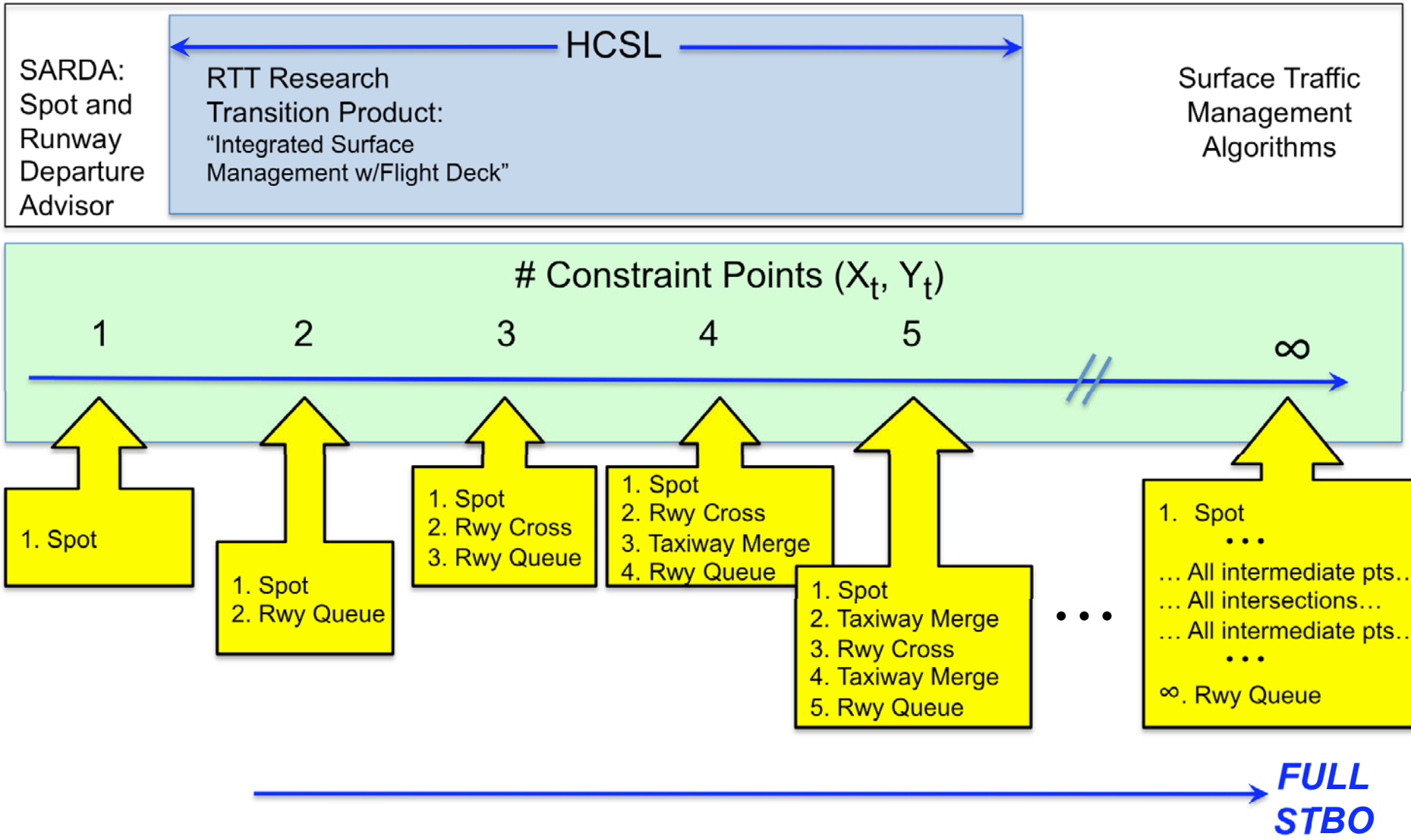
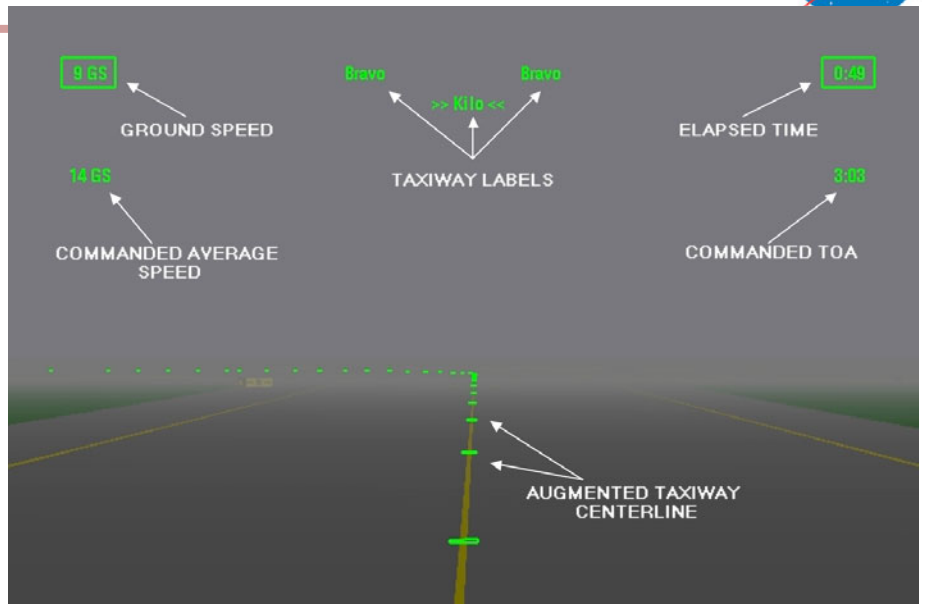


Simulation and Results

Pilot requirements for 4-D taxi clearances



Speed/Time Format (in green)

Initial Baseline 4-D Taxi Navigation Study

(Williams, Hooey & Foyle, 2006, Proc. AIAA)

- **18 Current Captains**
- **Minimal display information (baseline study)**
- **4-D Taxi Clearance Formats**
  - **Speed: Commanded average route speed + Current speed**
  - **Time: Commanded time to RWY + Elapsed time**
  - **Both: All**

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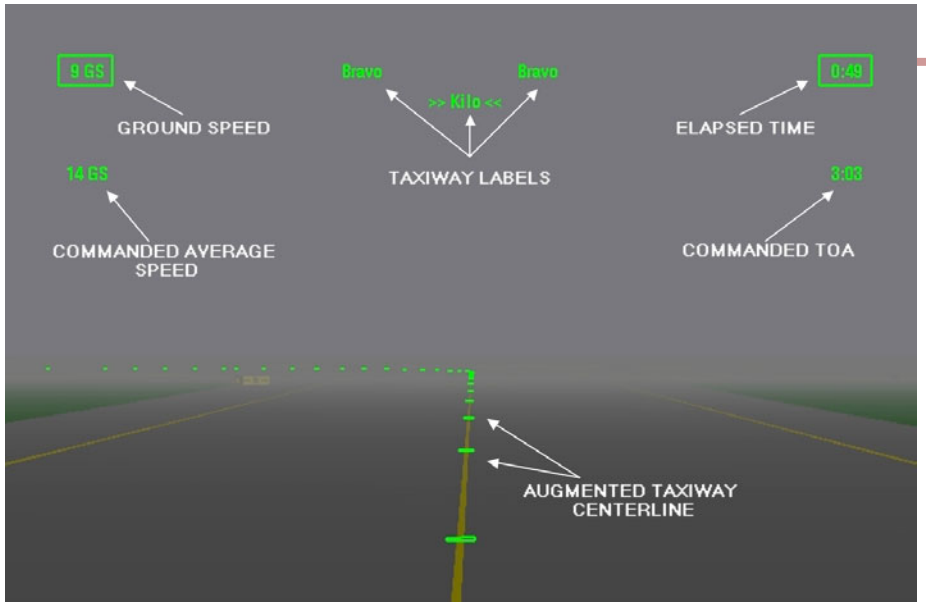

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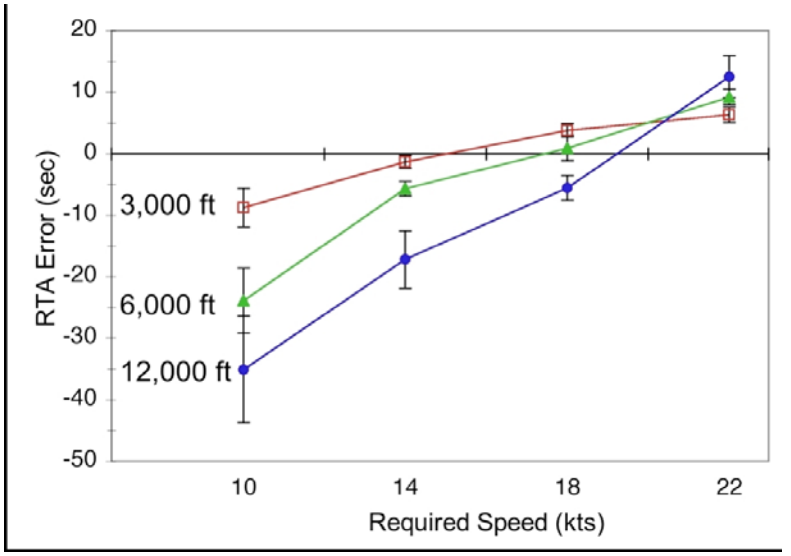

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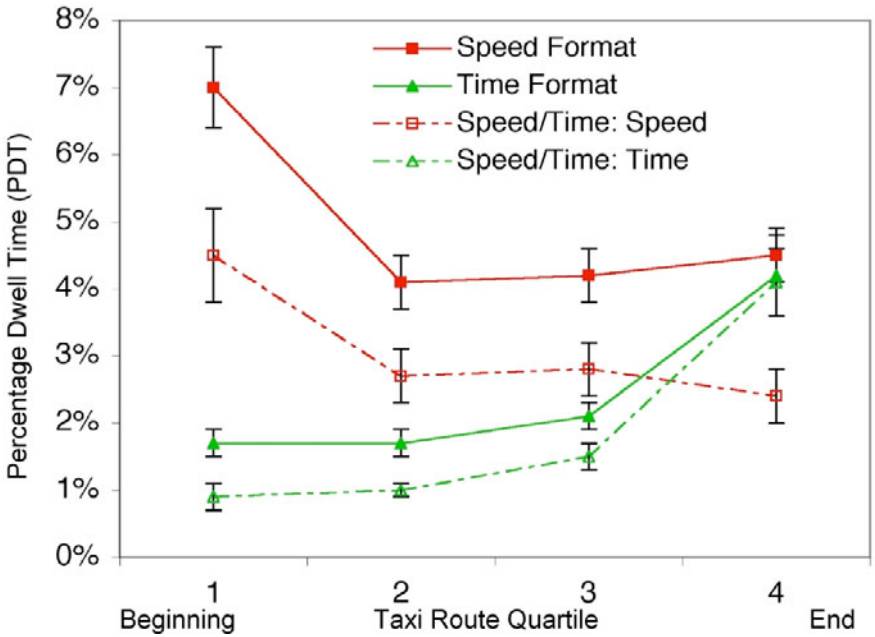
- **Results**
  - **Less error with Both (Time and Speed together) formatted clearances**
  - **Eyetracking usage - speed used early in route, then switch to using time information**



HCSL Completed NextGen Taxi Sims

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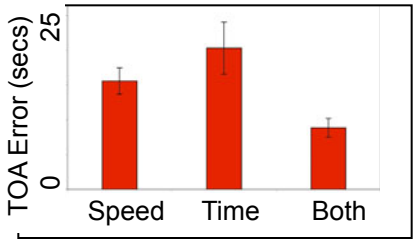
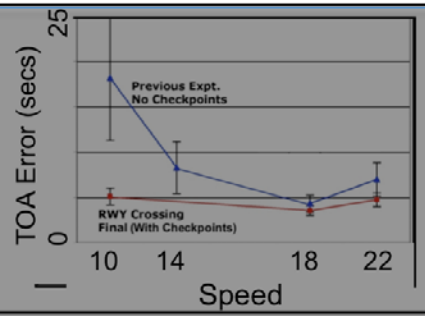
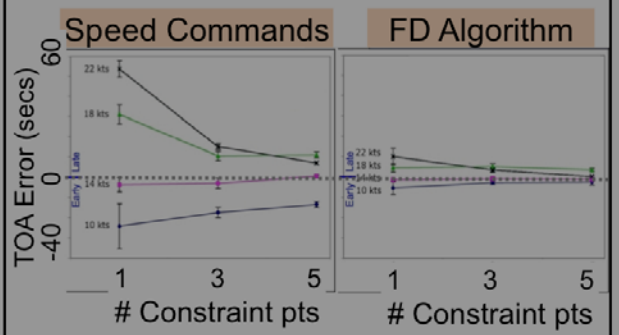
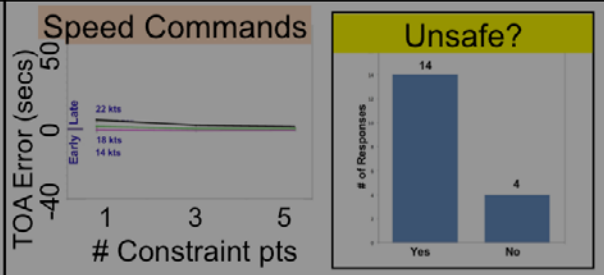
Taxi *information* needed: Speed, time, both? (18 CAs)		• Need both Speed (A/C control) and Time (RTA) information to meet RTAs	• Need FD displays • Need RTA in taxi clearance Customers: FAA, avionics/EFB mfg.
Intermediate *checkpoints* w/ speed+ time (18 CAs)		• Intermediate checkpoints (intersections, Rwy crossings) allow SMOs to "null error" for Rwy RTA	• Intermediate RTAs in taxi clearance help Customers: FAA, RTTs, SMO Develop.
ATC speed commands: Avionics/EFB need? (16 CA/FOs)		• ATC speed commands only → poor RTA conformance • Onboard speed recalc. → good RTA conformance	• Defined SMO algorithm parameters: Speed, Distance, # constraint pts • Initial FD display requirements Customers: FAA, avionics/EFB mfg., SMO Developers
ATC speed commands: Speed with conformance bands and defined A/C handling? (18 CA/FOs)		• ATC speed commands with defined A/C handling → good RTA conformance • *but* with 2-3x "eyes-in" time • Viewed as *not safe*	• ATC speed clearances will not suffice Customers: FAA, RTT

Simulation and Results

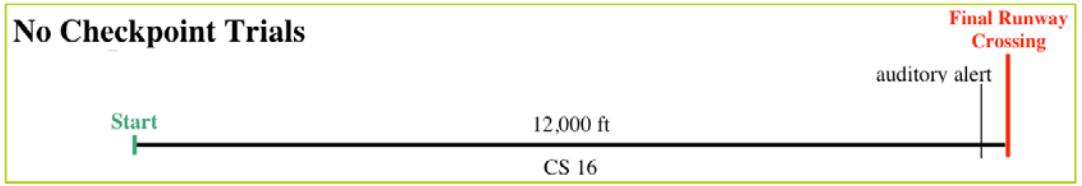
Pilot requirements for 4-D taxi clearances

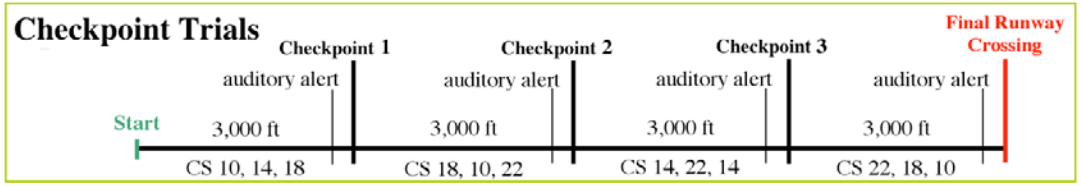
Initial Baseline 4-D Taxi Navigation Study (Expt #1) *(Williams, Hooey & Foyle, 2006, Proc. AIAA)*

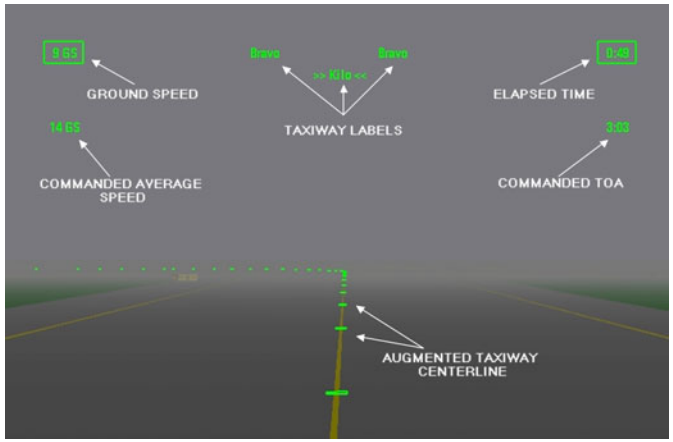
- Less error with Both (Time and Speed together) formatted clearances
- Eyetracking usage - speed used early in route, then switch to using time information

Baseline 4-D Taxi Navigation - Updating/adjusting 4-D taxi clearances study (Expt #2)

- Scenario: ATC Taxi clearance - Segmented ATC clearances w/ "time checkpoints" due to:
  1) changing conditions; or
  2) imperfect aircraft Time of arrival (TOA) compliance at checkpoints
- 17 Current Commercial Transport Captains
- Minimal display information (follow-on to first baseline study)
- 4-D Taxi Clearance Format:
  - Both: Commanded average SPEED + TIME to runway crossing (plus current readout)
- 6 experimental trials: 3 w/checkpoints & 3 no checkpoints
- Time checkpoints on EMM (white bars) & auditory tone 75 ft before checkpoint







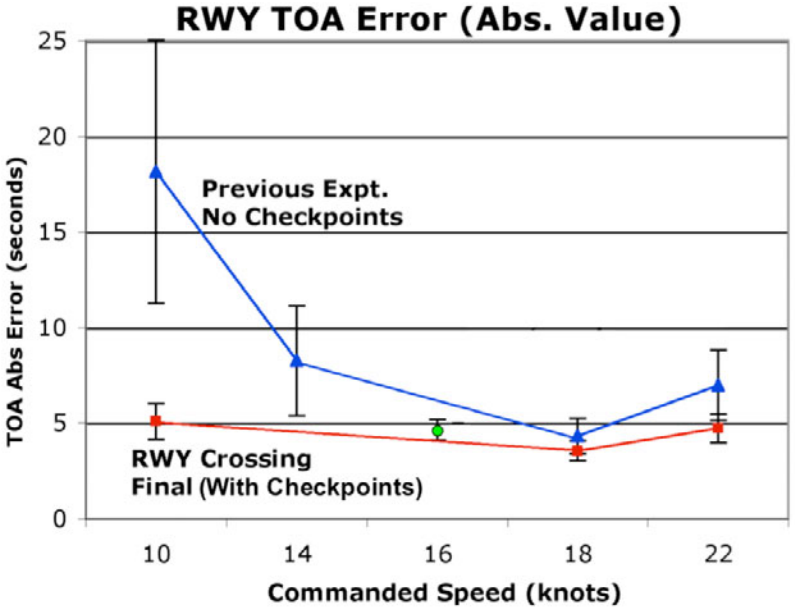
Pilot requirements for 4-D taxi clearances

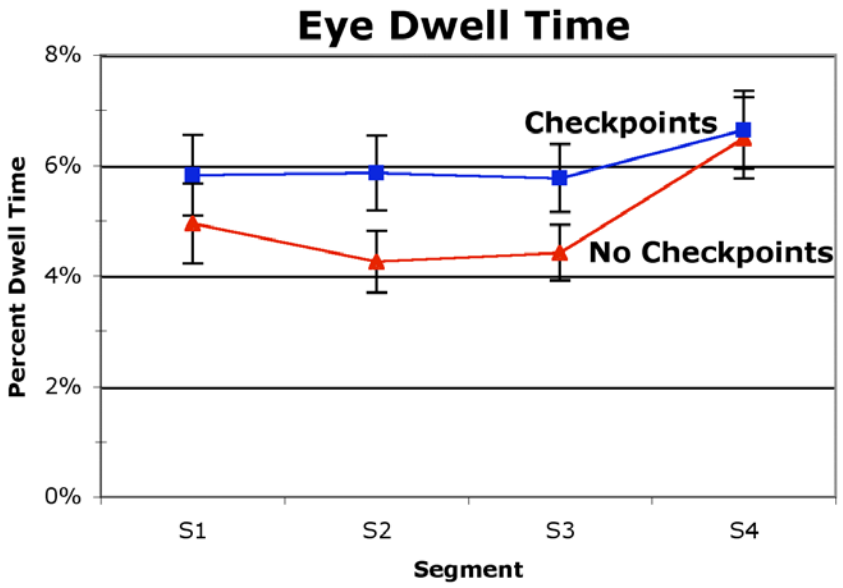
TOA Absolute Error (Left panel)

- For slower commanded taxi speeds, time checkpoints improve Runway (Time of Arrival) TOA accuracy

Eye Dwell Time (Right panel)

- Overall, pilots looked at display information more during checkpoint trials than non-checkpoint trials (24% vs 20% of trial)
- Middle-of-route checkpoints (Segments S2 & S3) --> more visual attention (% Dwell Time) on display
  - Pilots received new updated checkpoint information 4 times as often
  - Visual workload increased
  - Possible traffic awareness issues





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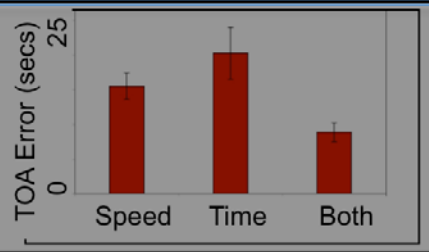
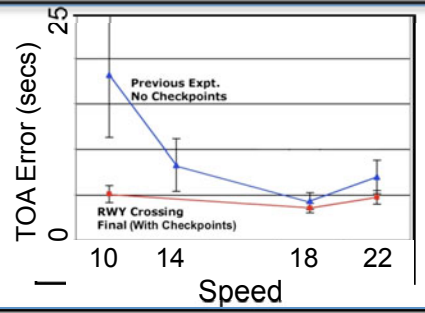
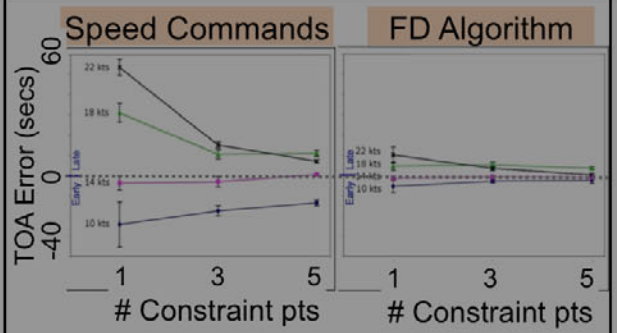
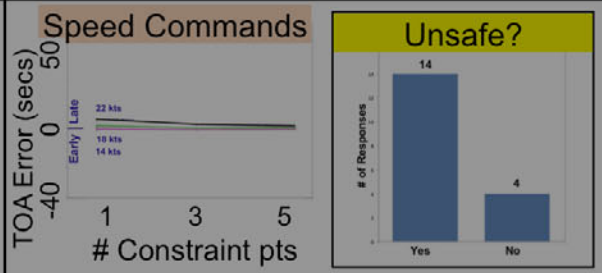
Taxi *information* needed: Speed, time, both? (18 CAs)		• Need both Speed (A/C control) and Time (RTA) information to meet RTAs	• Need FD displays • Need RTA in taxi clearance Customers: FAA, avionics/EFB mfg.
Intermediate *checkpoints* w/ speed+ time (18 CAs)		• Intermediate checkpoints (intersections, Rwy crossings) allow SMOs to "null error" for Rwy RTA	• Intermediate RTAs in taxi clearance help Customers: FAA, RTTs, SMO Develop.
ATC speed commands: Avionics/EFB need? (16 CA/FOs)		• ATC speed commands only → poor RTA conformance • Onboard speed recalc. → good RTA conformance	• Defined SMO algorithm parameters: Speed, Distance, # constraint pts • Initial FD display requirements Customers: FAA, avionics/EFB mfg., SMO Developers
ATC speed commands: Speed with conformance bands and defined A/C handling? (18 CA/FOs)		• ATC speed commands with defined A/C handling → good RTA conformance • *but* with 2-3x "eyes-in" time • Viewed as *not safe*	• ATC speed clearances will not suffice Customers: FAA, RTT

Simulation and Results

AP.2.S.09 - "NextGen Time-based Taxi Clearances" Pilot-in-the-loop simulation

Experiment Goal

Characterize the distribution of pilots' Time of Arrival (TOA) performance to inform the development of Surface Traffic Management (STM) algorithms.

Compare three STM system concepts (# traffic flow points; within-subjects factor):

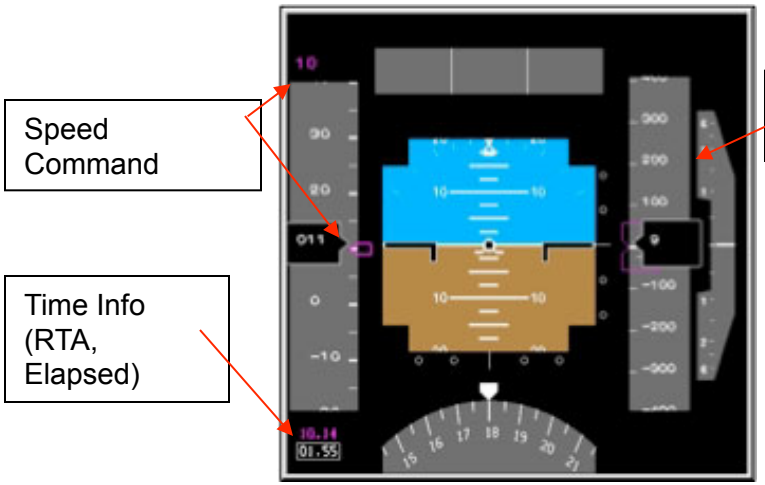
1) One single traffic flow point to ensure on-time arrival at the destination runway;
2) Occasional (three) traffic flow points to enable traffic sequencing at important intersections and
3) Frequent (five) traffic flow points to enable dynamic system re-optimizations and very close coordination

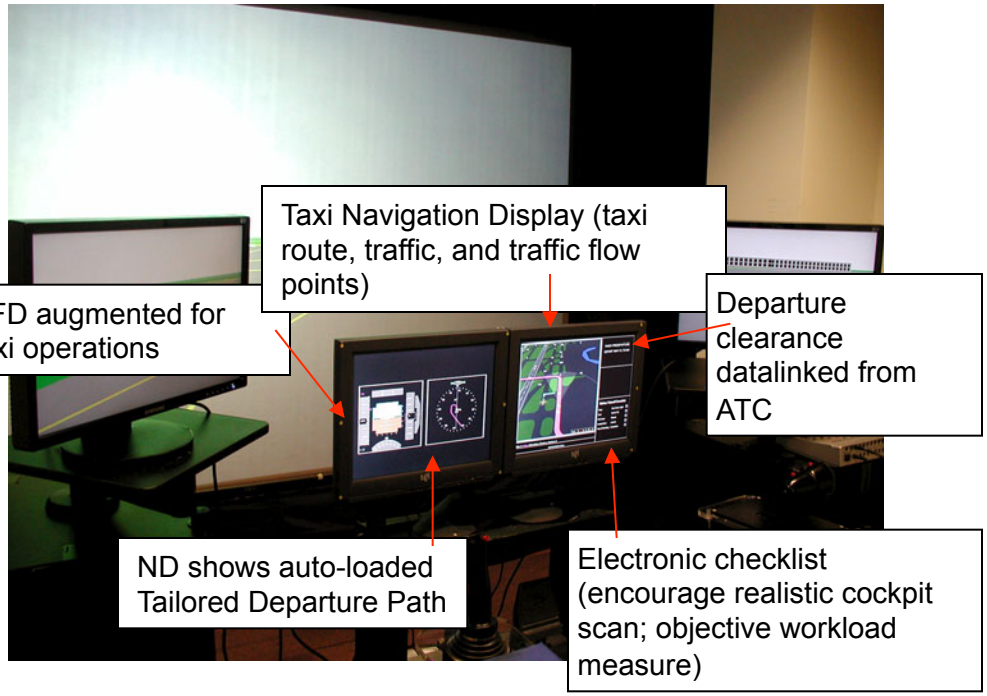
Compare two NextGen Time-based Taxi Ops implementations (Between-subjects factor):

1) Speed Clearances: Current-day Avionics without Speed Error Nulling
2) Speed & Time (Checkpoint) Clearances: Advanced Avionics with Speed Error Nulling

Experiment Overview

16 Pilots (Commercial Transport, CA & FO)
32 departure taxi trials ('spot' to runway)
Medium-fidelity simulator; DFW airport
Questionnaires; SME debriefs





AP.2.S.09: "NextGen Time-based Taxi Clearances" Pilot-in-the-loop simulation

Time of Arrival Error

Speed Effect:

- Slow speeds (10 kts): A/C early
- Fast speeds (18, 22 kts): A/C late
- 14 kts (negligible error)

Traffic Flow Point Effect:

- TOA error larger for 1 traffic flow point than for 3 and 5

Next-Gen Implementation Effect:

- TOA Error larger for "no error nulling"
- Reduced spread of TOA Error distribution with "error nulling"

Workload

- Error-nulling avionics increased time to verify/accept departure clearance (~ 1 sec for nominal clearance; 12 sec for off-nominal clearance with error)
- 2-3 speed/checkpoint updates recommended by pilots
- 5 updates viewed as too many for:

  Error nulling: 88%; 7 of 8
  No Error nulling: 0%: 0 of 6

  (p<.001, Performance/workload trade-off)

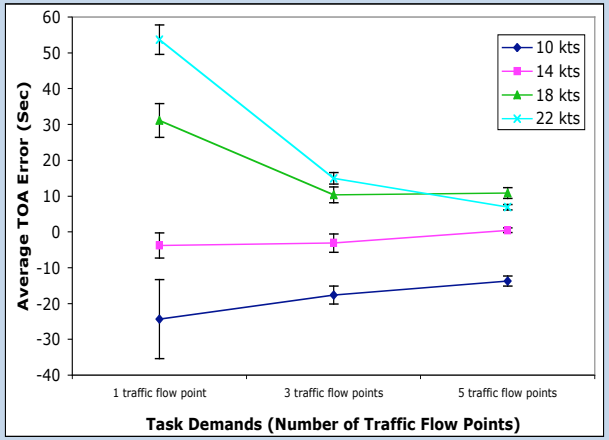
Structured Interview Results

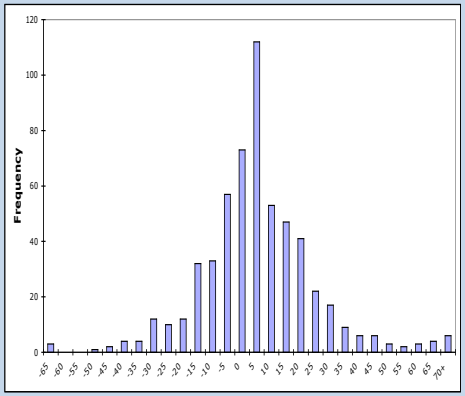
Safety: "eyes in" vs "eyes out"

NextGen Implementation:

- PFD appropriate and intuitive
- Taxi navigation display should show traffic and taxi hold instructions
- Increased cockpit coordination (i.e., "callouts" for speed & traffic)

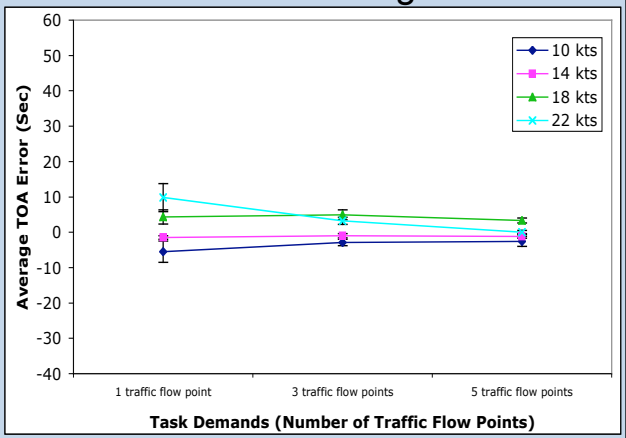
Next-Gen Implementation: Speed Clearance / No Error Nulling

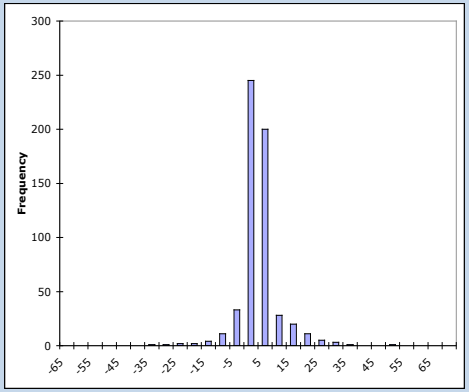




Distribution of TOA Errors

Next-Gen Implementation: Speed & Time Clearances / Error Nulling



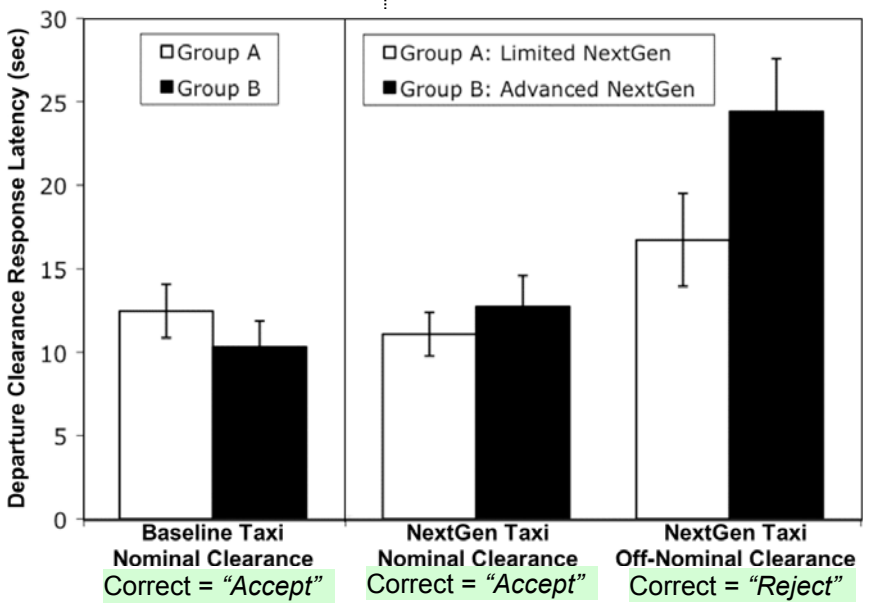


Distribution of TOA Errors

Average TOA Error = Actual TOA - Commanded TOA
Positive Error = Aircraft was late / too slow
Negative Error = Aircraft was early / too fast
(plotted with +/- 1 standard error)

Results inform STM Algorithm Development

Departure clearance operations under NextGen surface operations conditions



Compared to "current-day" baseline taxi,
Advanced NextGen (error-nulling avionics) had longer latencies to:
- Correctly accept correct clearances
- Correctly reject incorrect clearances

Compared to Limited NextGen (speed commands only),
Advanced NextGen (error-nulling avionics) had longer latencies to:
- Correctly reject incorrect clearances

May be indicative of increased workload in Advanced NextGen implementation

Structured Interview Results

- Datalinked direct upload (vs. manual FMS loading): Potential flightdeck workload savings
- "Tailored Departures / Unique Dynamic RNAV/RNP Departures": Clear advantages for system efficiency (re: Wx, winds, traffic) and individual aircraft efficiency (e.g., flight time, fuel savings)
- Need for verification of route (e.g., "NA227-123456), especially vs. SIDs implementations
- Issues:
  - How does flightdeck "back up" tailored departure routes in case of equipment failure, FMS dumping route, etc. (vs. Current SIDs with hard copy, FULL route information)
  - How does crew do pre-departure route briefing? (vs. Current SIDs with heading based turns, speeds, etc.)

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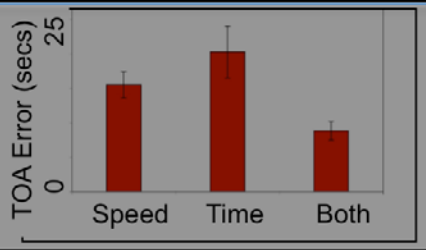
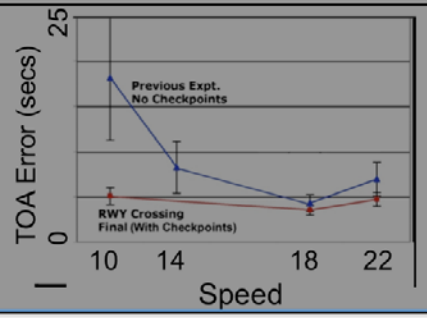
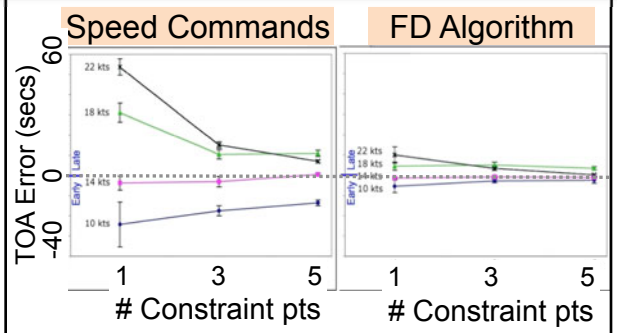
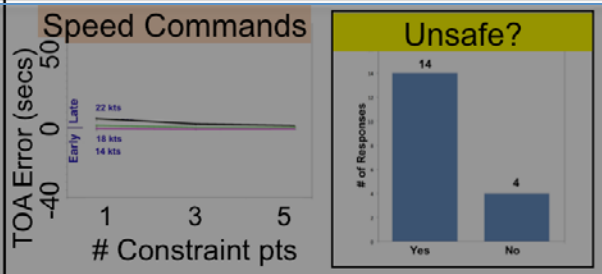
Taxi *information* needed: Speed, time, both? (18 CAs)		• Need both Speed (A/C control) and Time (RTA) information to meet RTAs	• Need FD displays • Need RTA in taxi clearance Customers: FAA, avionics/EFB mfg.
Intermediate *checkpoints* w/ speed+ time (18 CAs)		• Intermediate checkpoints (intersections, Rwy crossings) allow SMOs to "null error" for Rwy RTA	• Intermediate RTAs in taxi clearance help Customers: FAA, RTTs, SMO Develop.
ATC speed commands: Avionics/EFB need? (16 CA/FOs)		• ATC speed commands only → poor RTA conformance • Onboard speed recalc. → good RTA conformance	• Defined SMO algorithm parameters: Speed, Distance, # constraint pts • Initial FD display requirements Customers: FAA, avionics/EFB mfg., SMO Developers
ATC speed commands: Speed with conformance bands and defined A/C handling? (18 CA/FOs)		• ATC speed commands with defined A/C handling → good RTA conformance • *but* with 2-3x "eyes-in" time • Viewed as *not safe*	• ATC speed clearances will not suffice Customers: FAA, RTT

Simulation and Results

Milestone AP.2.S.11

Assess System Performance of Varying Options for 4D Taxi Clearance Information to Provide a Scientific Basis for Future Systems Requirements for Mature Surface Automation and Arrival/Departure Seamless Airspace Transition

ConOps: "ATC Voice Taxi Clearances with Speed Commands"

Pilots: 18 commercial transport Captains (current or recent retirees)

Scenario: DFW Taxi out to take off – Ramp parking spot to runway through take-off roll (up to 80 kts)

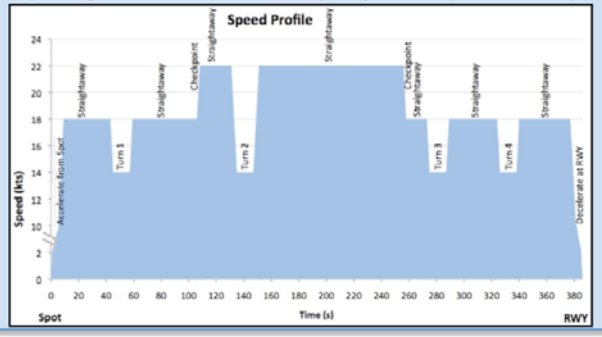
Concept Scope

Trajectory-Based Surface Operations

Taxi out operations with:

- ATC *voice speed commands*
- Pilots required *speed range compliance* of +/- 1.5 kts
- Pilot *acceleration profile control* requirement
- Pilot crosscheck of dynamic RNAV routes datalinked to cockpit (waypoints/crossing restrictions)

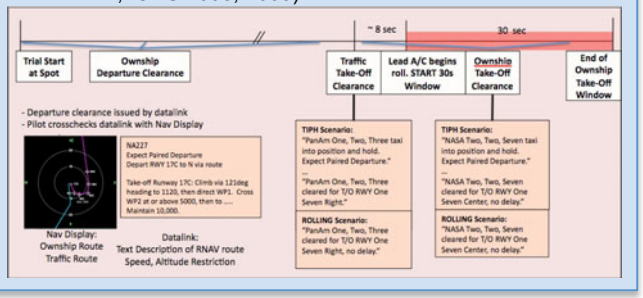
A/C dynamics: 2 kts/sec spool up/down; 14 kts turns; Max. acceleration of: 0.25g long.; 0.15g lateral (Cheng, Sweriduk, Yeh, Andre & Foyle; AIAA) GNC, 2008)



NextGen Paired Departures

- Closely spaced parallel paired departures - (MITRE/ Lunsford; ICNS 2008, 2009)
- Ownship informed of paired departure via datalink, paired aircraft's route depicted on Navigation Display

NextGen Paired Departure Concept (After Lunsford/ MITRE, ICNS 2008, 2009)



Milestone AP.2.S.11

Assess System Performance of Varying Options for 4D Taxi Clearance Information to Provide a Scientific Basis for Future Systems Requirements for Mature Surface Automation and Arrival/Departure Seamless Airspace Transition

- Time of Arrival (TOA) Error to traffic flow points is improved compared to previous study (40-60 secs TOA error, Foyle et al, 2009) - because of defined aircraft acceleration and speed range requirements *…BUT…*

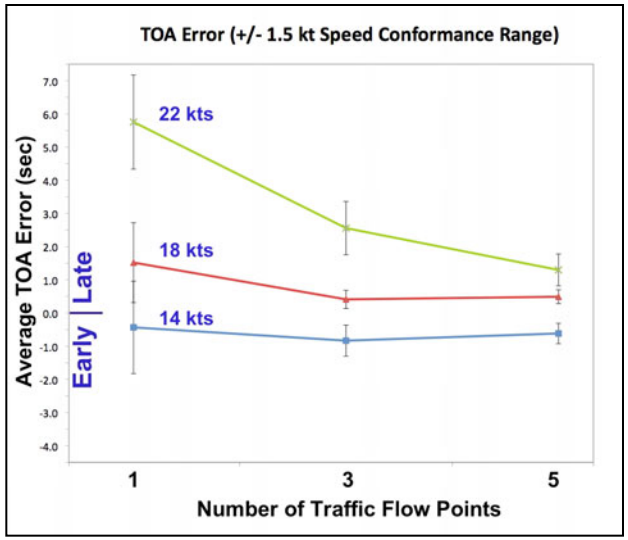
- Workload and safety level were *unacceptable*

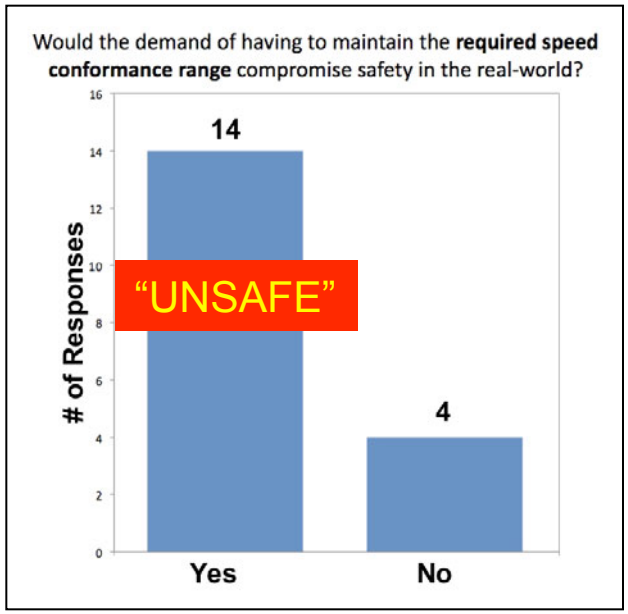
- Likely due to increased requirements of taxi task (Acceleration profile, speed range requirement)

- 14 of 18 pilots responded that speed conformance range restriction would compromise safety (p = .018)
- Rated more difficult than current actual taxi operations (p = .042)
- Eyes-in time 18-24% compared to 8% baseline
- Responded that they were "frequently" focused on the PFD speed tape when needed to attend to the taxiway

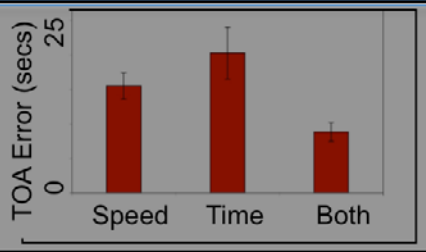
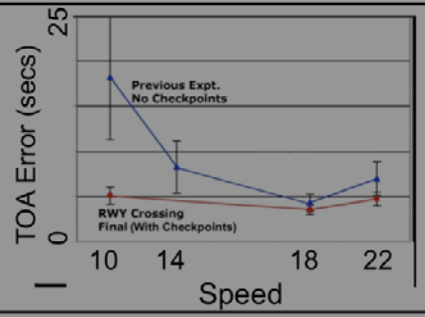
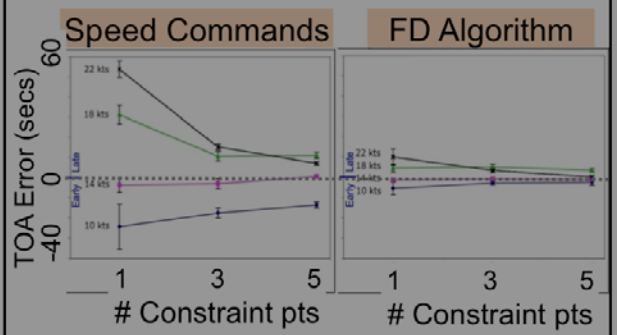
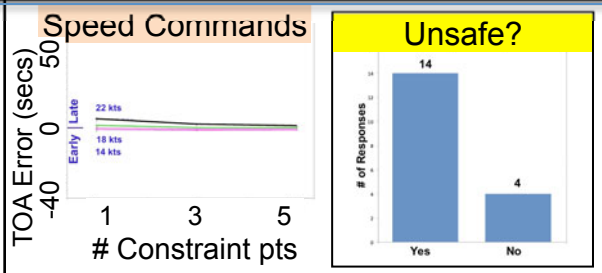
IMPACT

- ConOps of ATC providing taxi clearances with speed (via ATC DST) is not workable
- Need for RTA in taxi clearance; flight deck displays

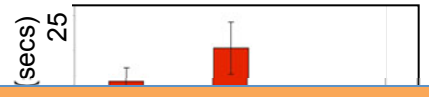
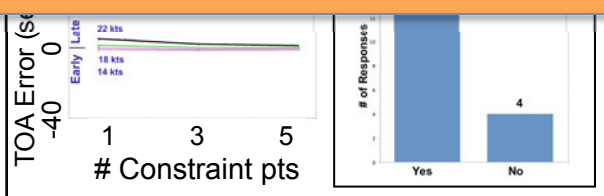




HCSL Completed NextGen Taxi Sims

Evaluated	Results	Findings	ConOps Implications
Taxi *information* needed: Speed, time, both? (18 CAs)		• Need both Speed (A/C control) and Time (RTA) information to meet RTAs	• Need FD displays • Need RTA in taxi clearance Customers: FAA, avionics/EFB mfg.
Intermediate *checkpoints* w/ speed+ time (18 CAs)		• Intermediate checkpoints (intersections, Rwy crossings) allow SMOs to "null error" for Rwy RTA	• Intermediate RTAs in taxi clearance help Customers: FAA, RTTs, SMO Develop.
ATC speed commands: Avionics/EFB need? (16 CA/FOs)		• ATC speed commands only → poor RTA conformance • Onboard speed recalc. → good RTA conformance	• Defined SMO algorithm parameters: Speed, Distance, # constraint pts • Initial FD display requirements Customers: FAA, avionics/EFB mfg., SMO Developers
ATC speed commands: Speed with conformance bands and defined A/C handling? (18 CA/FOs)		• ATC speed commands with defined A/C handling → good RTA conformance • *but* with 2-3x "eyes-in" time • Viewed as *not safe*	• ATC speed clearances will not suffice Customers: FAA, RTT

HCSL Completed NextGen Taxi Sims

Evaluated	Results	Findings	ConOps Implications
Taxi *information* needed time, bc (18 CAs)		• Need both Speed (A/C	• Need FD displays clearance FB mfg.
Intermed *checkp* speed+ (18 CAs)			As in taxi Develop.
ATC spe comma Avionic (16 CA/F			gorithm ed, traint pts FB mfg., s
ATC spe comma with conformance bands and defined A/C handling? (18 CA/FOs)		defined A/C handling → good RTA conformance • *but* with 2-3x "eyes-in" time • Viewed as *not safe*	not suffice Customers: FAA, RTT ances will

Conclusion: What do we know re: ConOps?

1) Surface Traffic Managment System ← Sim data (TOA error, variability) of taxi speed, route length, # constraint points
2) ATC Clearance: Recommend 1 ≤ # intersection constraint points ≤ 4
3) ATC Clearance: Time (RTAs) necessary but not sufficient
4) ATC Clearance/Flight Deck: Taxi clearances with speed not safe/workable with current-day flight deck
5) Flight Deck: Need flight-deck display (avionics/EFB) capability

Next Steps: HCSL NextGen Taxi Sims

Conclusion: What do we know re: ConOps?

1) Surface Traffic Management System ← Sim data (TOA error, variability) of taxi speed, route length, # constraint points
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5) Flight Deck: Need flight-deck display (avionics/EFB) capability

Overall Research Objectives

Expand ConOps to address:

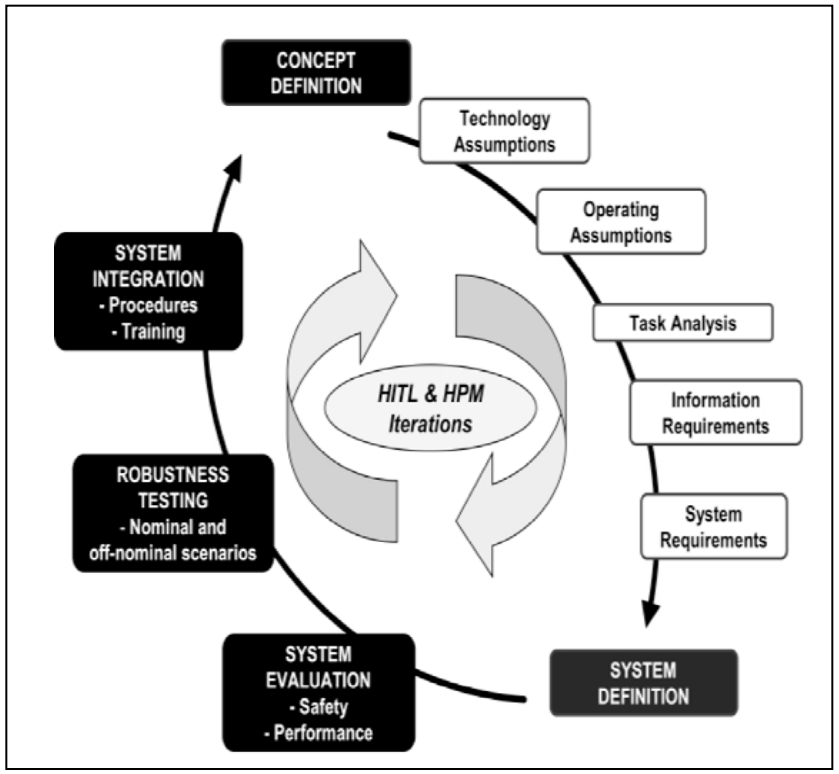
- Flight Deck Avionics/EFBs
- Traffic management

Specific Plan

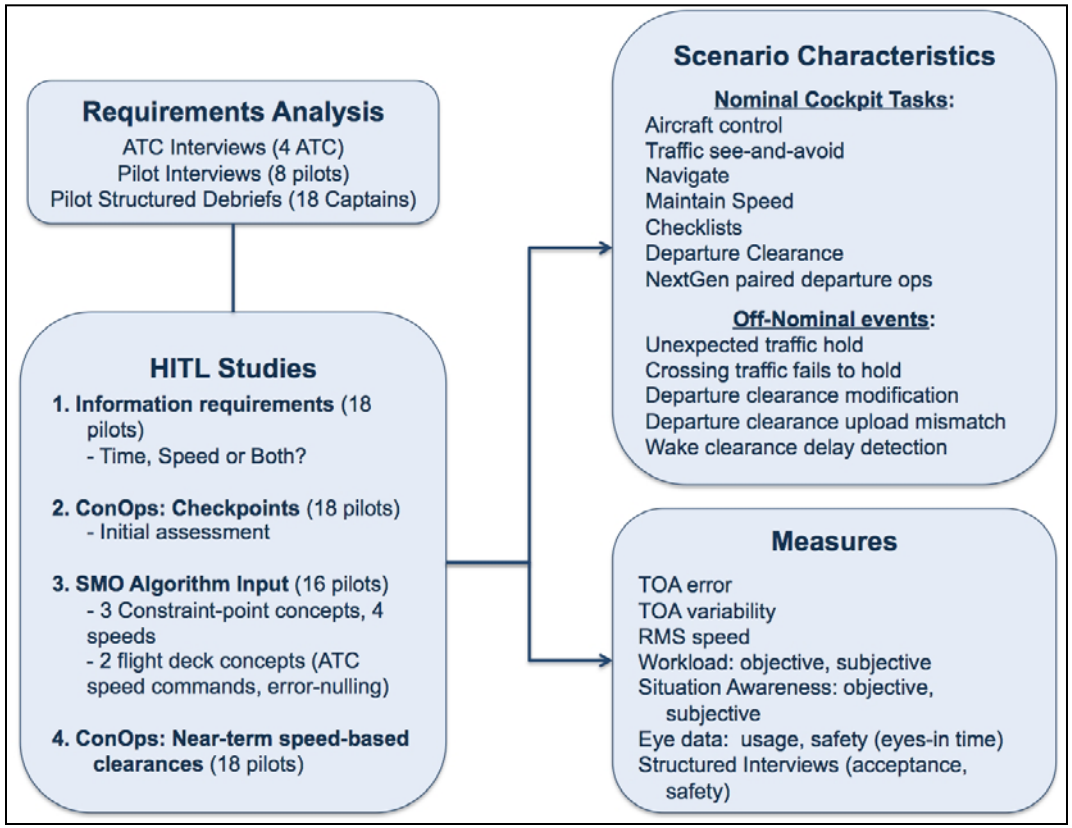
- FY11 Simulations
  - Sim #1 – Timing/format parameters for Data Comm vs. Voice trades for taxi re-routing
  - Sim #2 - Initial look at RTT RTP "Integrated Surface Management w/ Flight Deck"
    - a) Evaluate Flight Deck Display concepts x Traffic Flow concepts
    - b) Increase scenario complexity (traffic conditions, ATC-revised Rwy RTAs)
- FY12 sims – Advanced flight deck concepts to enable SMO re-optimizations
- FY13 – SMS / Flight Deck Integration sims
  - a) Evaluate Flight Deck concept elements (# Constraint Points + Flightdeck + Traffic) defined in previous sims with actual SMS algorithms (informed by sims)
- FY14-15 sims – Develop RTT RTP "Integrated Surface Management w/ Flight Deck"

Backup Slides

Research Approach



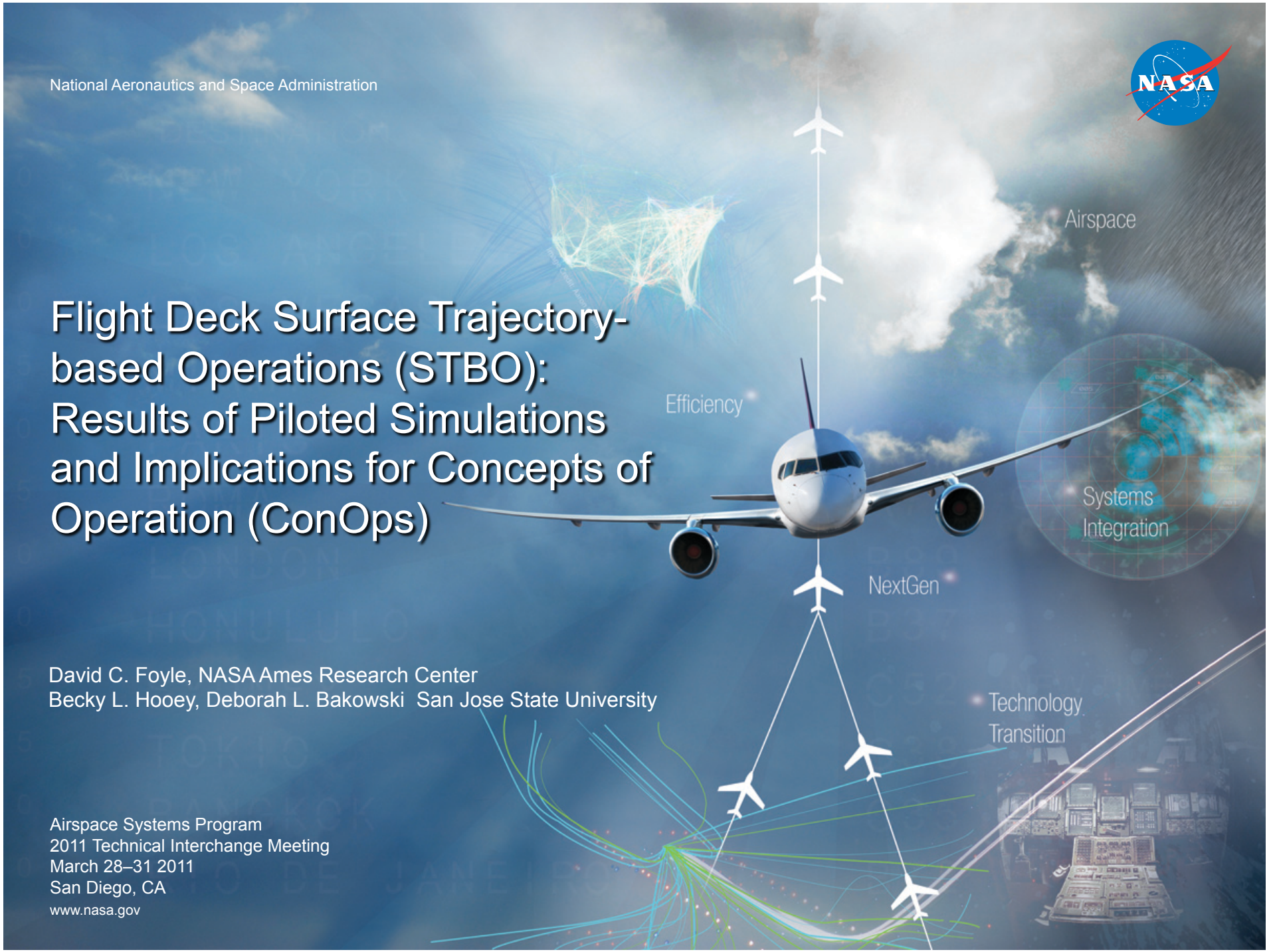
Human-centered design and evaluation process
(from Foyle & Hooey, 2008)



NextGen Pilot Taxi Operations HITL Research Approach

Off-nominal Methodology Papers:
Foyle & Hooey (2003). ISAP Conference.
Newman & Foyle (2003). ISAP Conference.
Foyle, Newman & Hooey (2005). NATO Conference.

National Aeronautics and Space Administration



Flight Deck Surface Trajectory-based Operations (STBO): Results of Piloted Simulations and Implications for Concepts of Operation (ConOps)

David C. Foyle, NASA Ames Research Center
Becky L. Hooey, Deborah L. Bakowski San Jose State University

Airspace Systems Program
2011 Technical Interchange Meeting
March 28–31 2011
San Diego, CA
www.nasa.gov

Research Focus: Pilot requirements for Surface Trajectory Based Operations (STBO) clearances

Objective

STBO to enable NextGen flight deck operations to support:

• NextGen Arrival - Anticipated throughput generated by NextGen concepts such as M&S, VCSPA, etc.

• NextGen Departure - Predictability required for NextGen concepts (e.g., Rwy; Merge; Flow) (ref: IADS RTT ConOps 4-12-10)

Must work ATC concepts in parallel with flight deck concepts

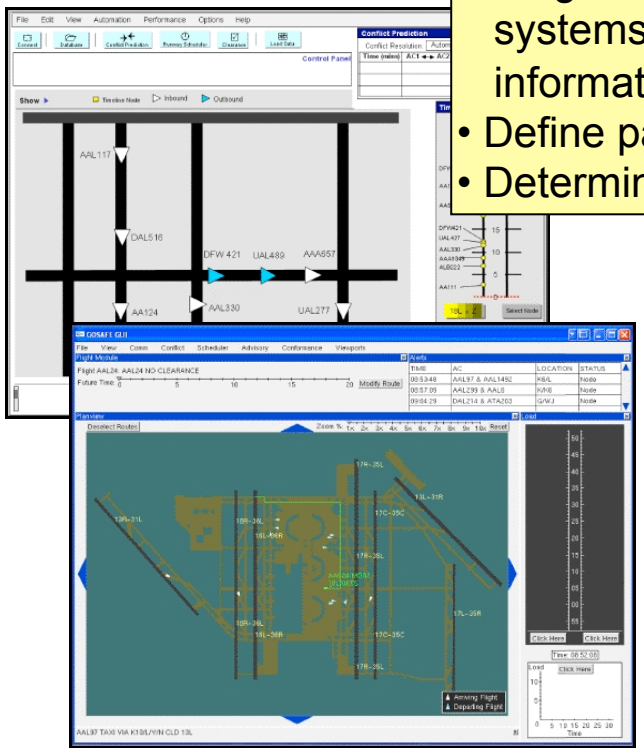
• Otherwise, vulnerability to risk of developing concepts to which pilots cannot comply (ref: IADS RTT Doc: "OV-6c NEXTGEN 2018 Scenario07 / Peak Departures v0.1 4-13-2009")

Goals:

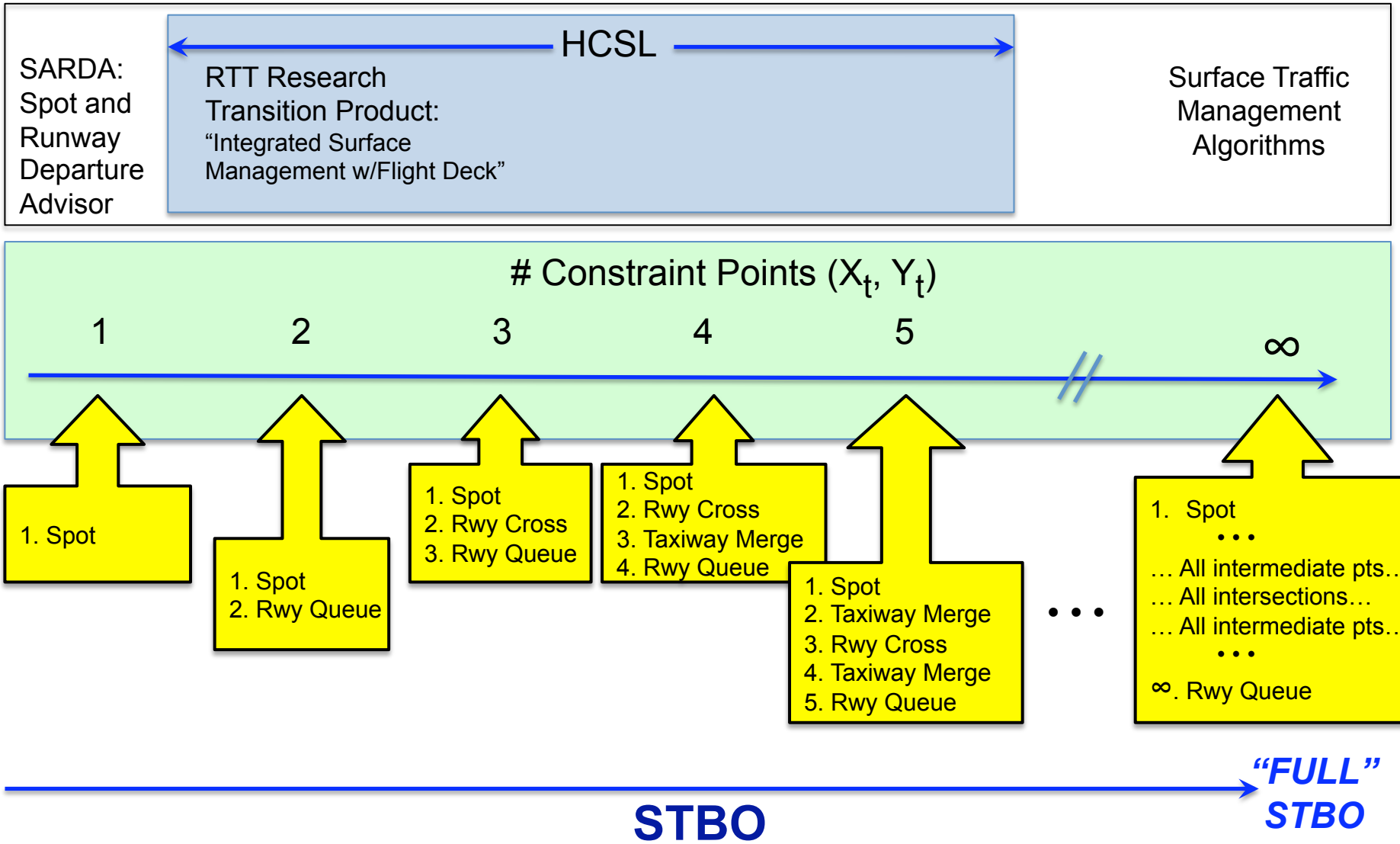
• Integrate Surface Traffic Management (STM) systems' STBO clearances with flight deck information requirements

• Define parameters for flight deck and STM system

• Determine ConOps for STBO



NextGen Taxi / Surface Trajectory-Based Operations (STBO)



Flight Deck Simulations and Results

Experiment 1: Commanded Speed – Without Speed Profiles or Conformance

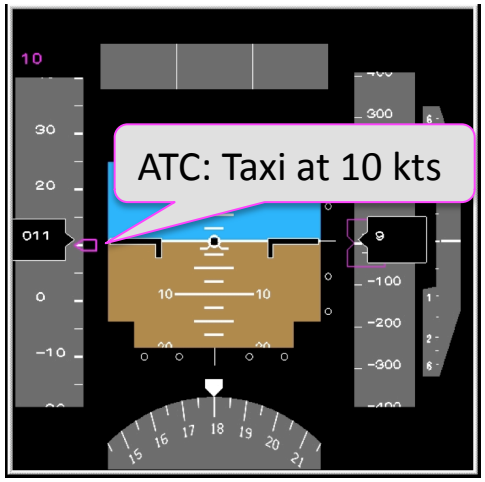
Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS

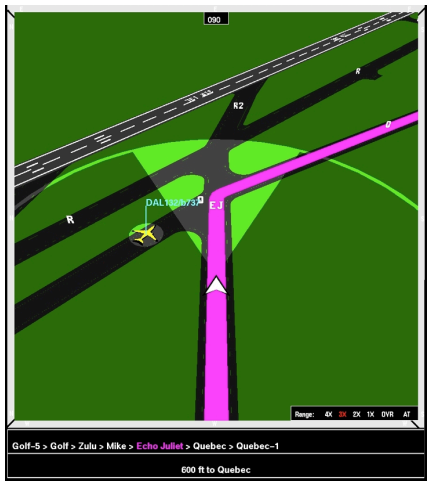
Objective: "Minimum Flight Deck Equipage" ConOps Evaluation

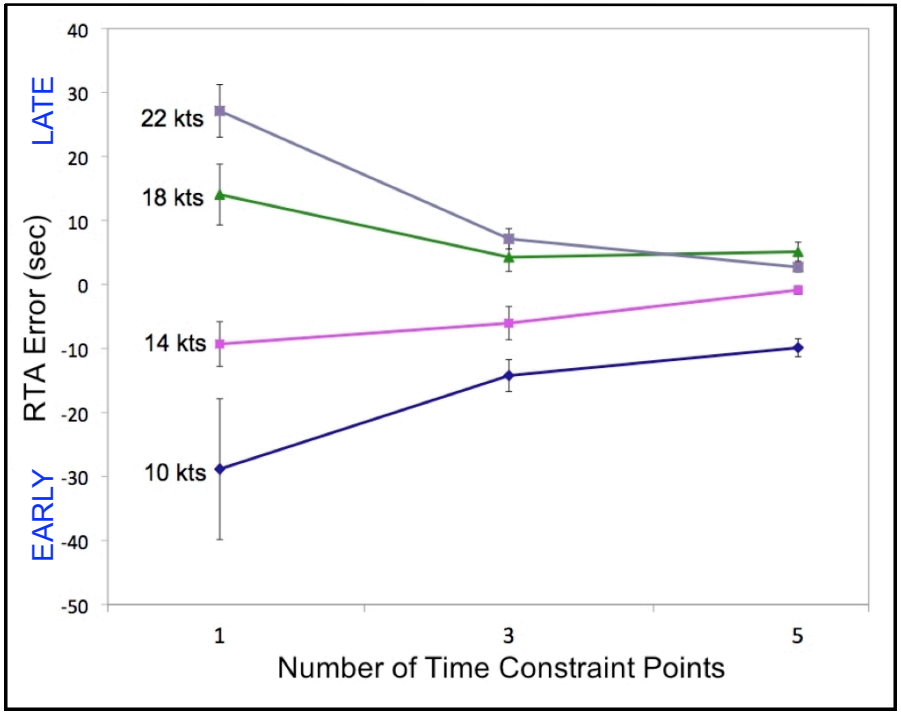
1) ATC provides 'A/C required speed' in taxi clearance (either automated or ATC Decision Support Tool)
2) Pilots not required to follow specific acceleration/deceleration speed profiles (only "be aggressive")

- 8 Current or recently retired pilots: 6 CAs; 2 FOs
- STBO Taxi Clearances – manipulated:
  - **Speed**: Taxi clearance included required speed
  - **# Intermediate Time Constraint Points**

- Results
  - More RTA error with 1 time constraint point
  - Less RTA error with 3 or 5 time constraint points
  - Slower required speeds → early arrival; Faster required speeds → late arrival







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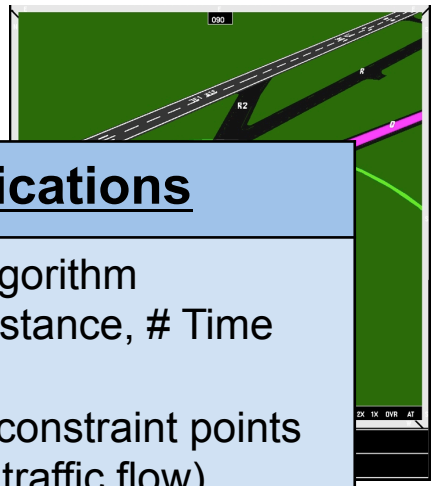
required speeds → late arrival



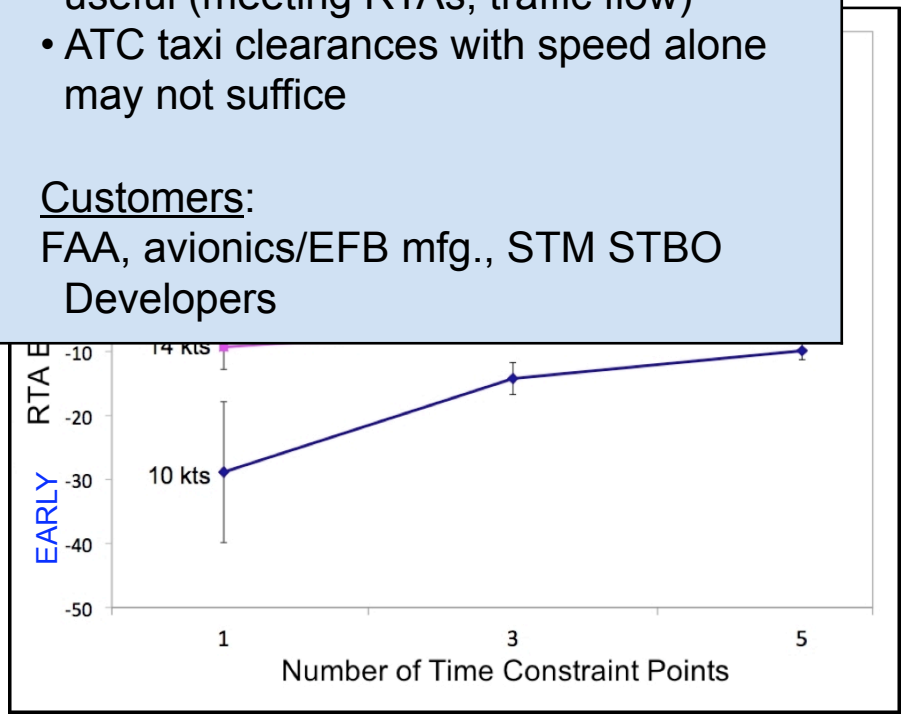
Findings

- ATC taxi clearances with speed → poor RTA conformance

ConOps Implications

- Defined STM STBO algorithm parameters: Speed, Distance, # Time constraint points
- Intermediate taxi time constraint points useful (meeting RTAs, traffic flow)
- ATC taxi clearances with speed alone may not suffice

Customers:
FAA, avionics/EFB mfg., STM STBO Developers



Experiment 2: Commanded Speed – With Speed Profiles/Conformance Range

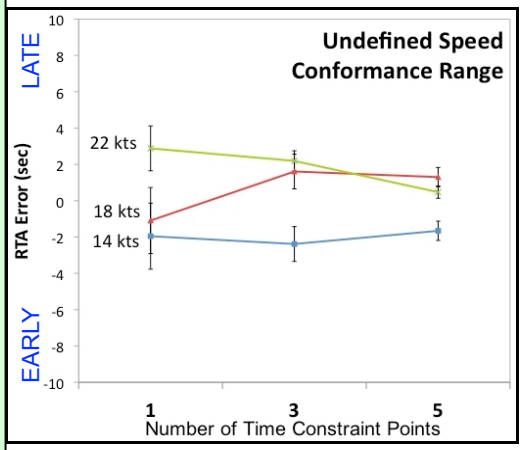
Bakowski, Foyle, Kunkle, Hooey & Jordan, 2011, ISAP

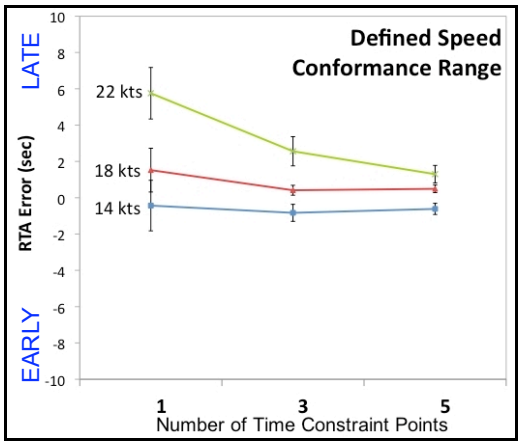
Objective: "Minimum Flight Deck Equipage" ConOps Evaluation

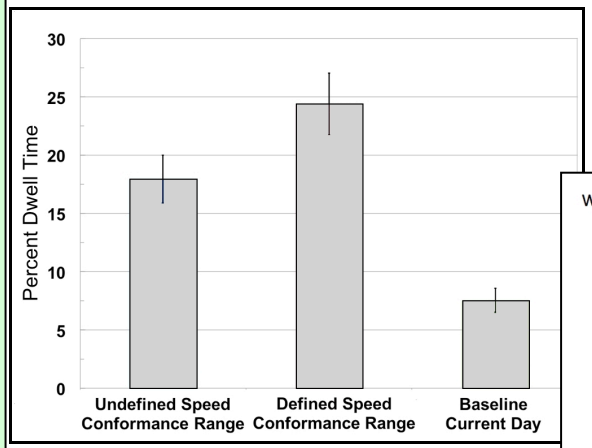
1) ATC provides 'A/C required speed' in taxi clearance (either automated or ATC Decision Support Tool)
2) Pilots required to follow specific acceleration/ deceleration speed profiles (2 kts/sec accel./ decel.)
3) Investigated speed conformance tolerance

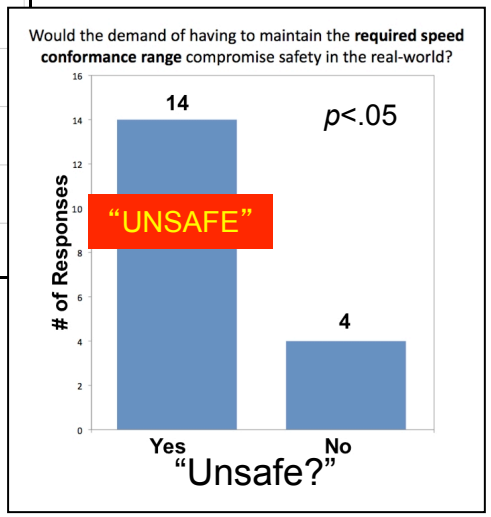
- 18 Current/recently retired pilots: 13 CAs; 5 FOs
- STBO Taxi Clearances – manipulated:
  - **Speed**: Taxi clearance included required speed
  - **# Intermediate Time Constraint Points**
  - **Speed Conformance Range:**
    Undefined (tested first) / Defined (+/- 1.5 kts); Current-Day Baseline

- Results
  - Improved RTA error (because of defined aircraft acceleration and speed range requirements ***BUT…***
  - Visual workload and safety level were ***unacceptable***









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    Current-Day Baseline

- Results
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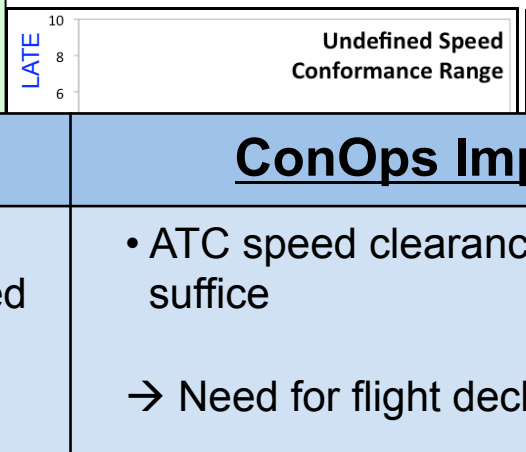
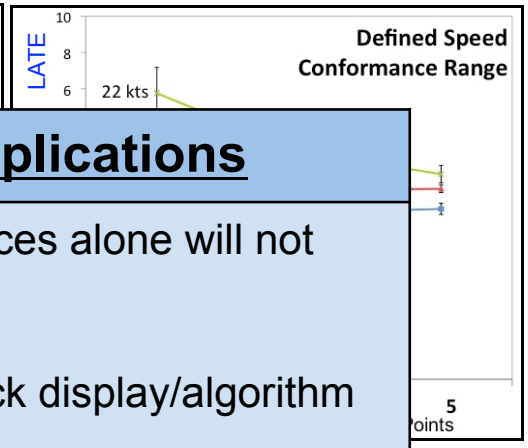
  - Visual workload and safety level were ***unacceptable***





Findings

ATC taxi clearances with speed:

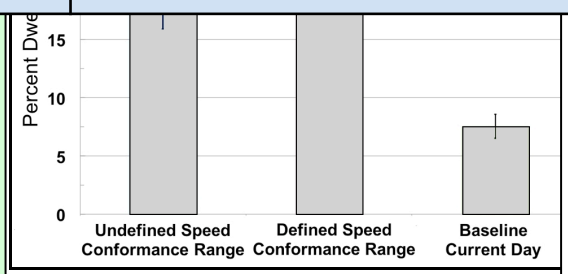
- Poor RTA conformance without speed accel./decel. profiles
- Good RTA conformance with speed accel./decel. profiles, *but*
  - with 2-3x "eyes-in" time
  - viewed as *not safe*

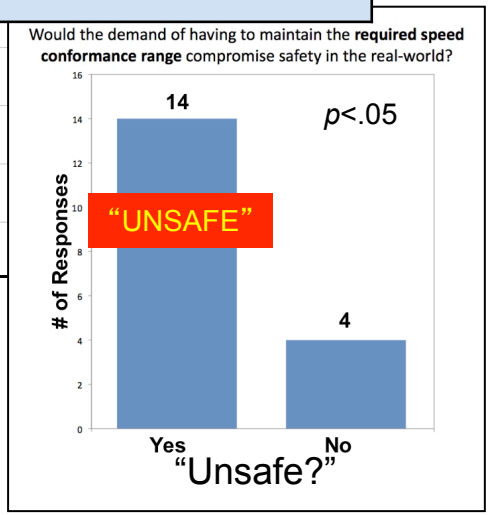
ConOps Implications

- ATC speed clearances alone will not suffice

→ Need for flight deck display/algorithm

Customers:
FAA, RTT





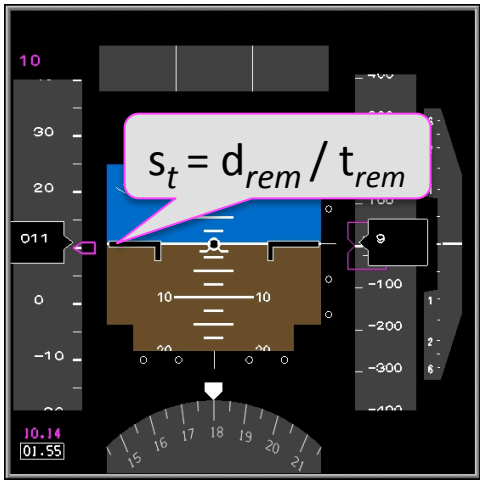
Experiment 3: Error-nulling algorithm/display

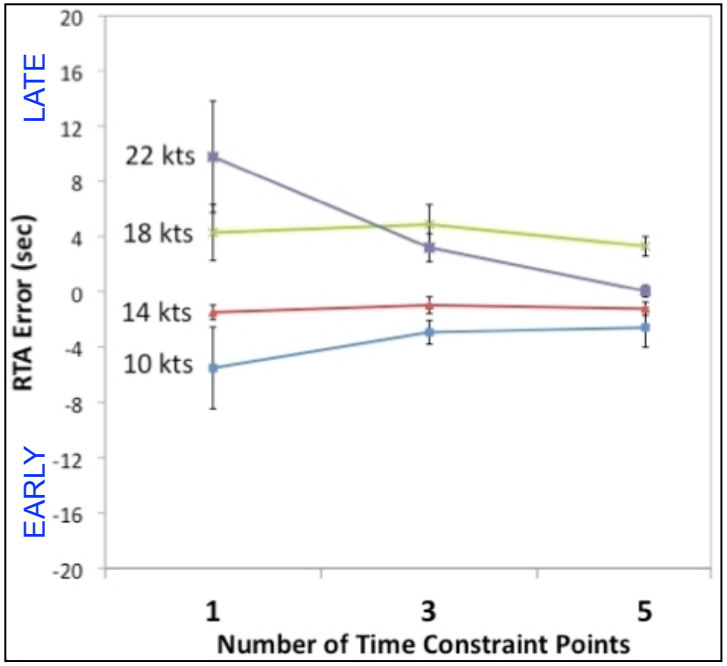
Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS

Objective: "Flight Deck Equipage" ConOps Evaluation

1) ATC provides taxi clearance with RTA
2) Flight deck equipage (Avionics or EFB, electronic flight bag)

- 8 Current or recently retired pilots: 7 CAs; 1 FO
- Displays (PFD; Taxi Nav. Display, TND)
  - **PFD**: RTA time-to-go; Elapsed time; Algorithm: Speed required to meet RTA (Enables *strategic* usage)
  - **TND**: Route; Time constraint point
- STBO Taxi Clearances – manipulated:
  - Speed
  - # Intermediate Time Constraint Points
- Results
  - Display/algorithm with speed recalculation → good RTA conformance





Experiment 3: Error-nulling algorithm/display

Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS

Objective: "Flight Deck Equipage" ConOps Evaluation

1) ATC provides taxi clearance with RTA
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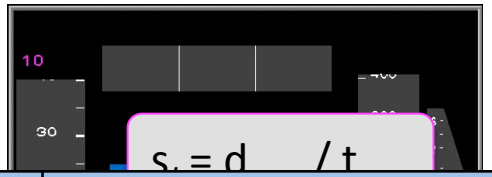
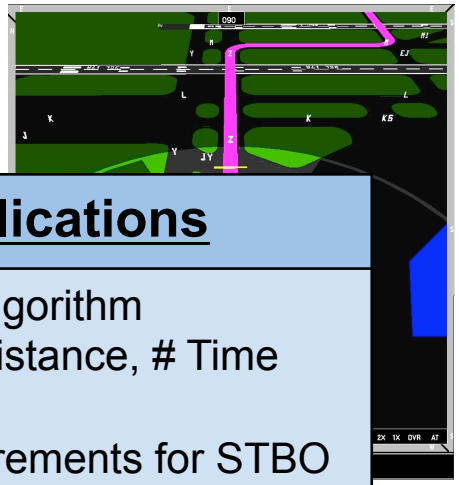
    → good RTA conformance





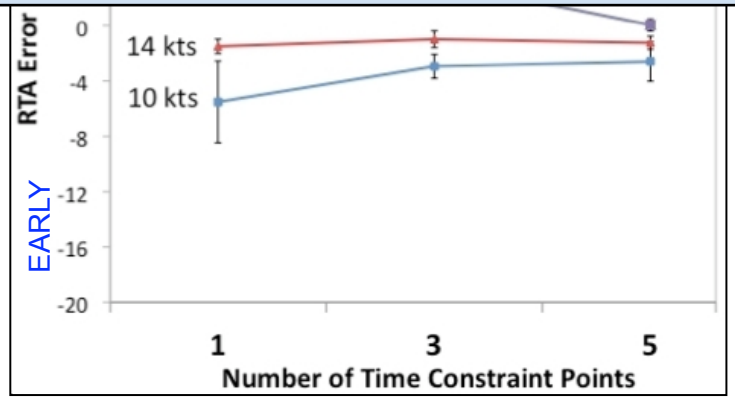
Findings

- Flight deck algorithm: Speed recalculation → good RTA conformance

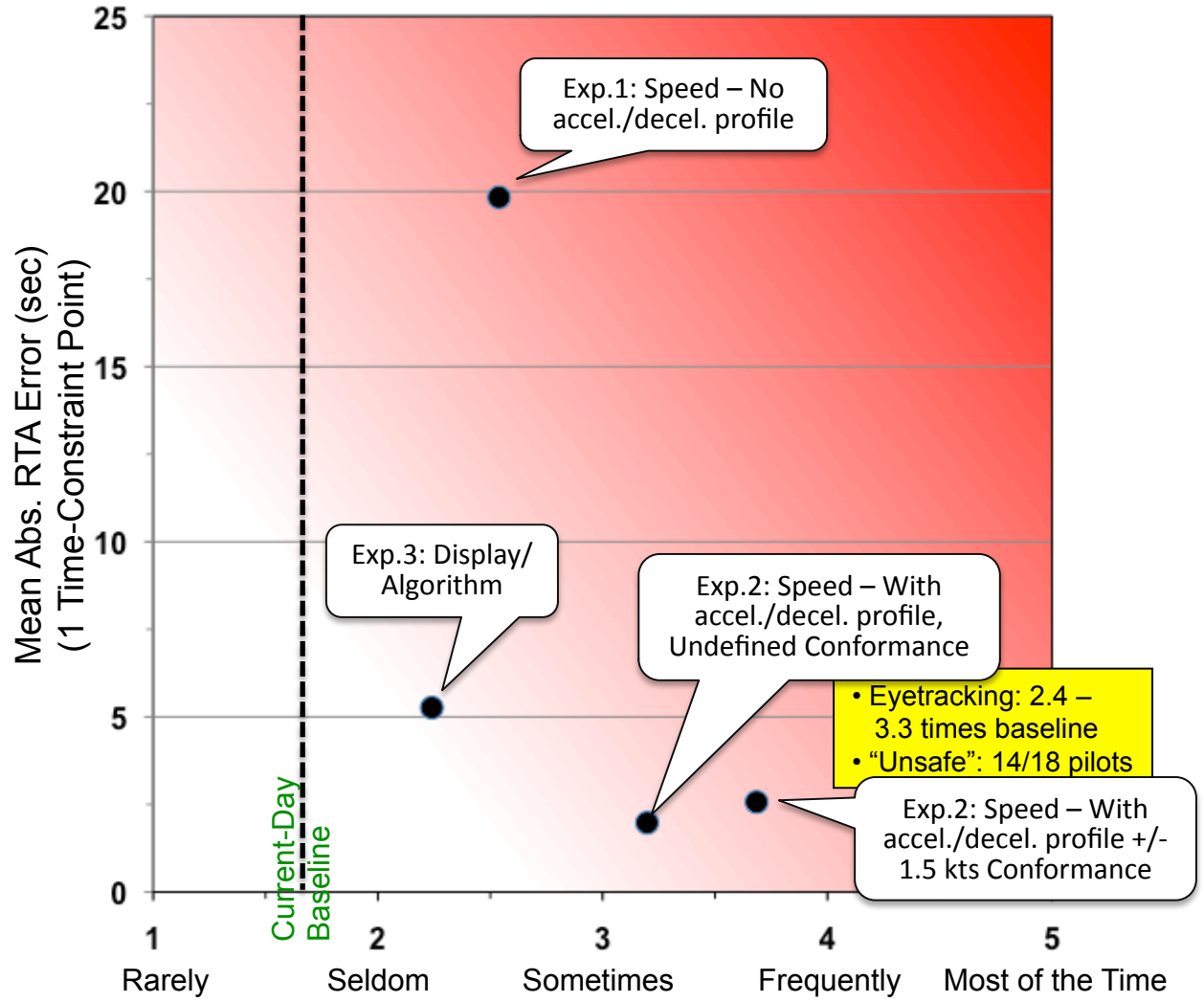
ConOps Implications

- Defined STM STBO algorithm parameters: Speed, Distance, # Time constraint points
- Initial flight deck requirements for STBO ConOps

Customers:
FAA, avionics/EFB mfg., STM STBO Developers



Cross-Studies: Usage/Safety Implications



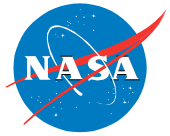
"How often did you find yourself ***focusing on the PFD Speed or Time*** display, when you ***should have been paying attention to the external taxiway environment***?"

Summary / Overall ConOps Implications

Summary Findings	ConOps Implications
• STBO clearances with speed are not viable solution • Taxiing Captain cannot "tightly control/ track" speed, navigate, and maintain separation • Only flight deck algorithm/display condition → Good RTA conformance AND appropriate visual workload / safety *Caveat:* Flight deck algorithm/display -- Needs to allow "strategic operation", not "tight control/tracking"	• Requirement for *human-centered** flight deck display/algorithm for STBO Customers: FAA, avionics/EFB mfg., STM STBO Developers ***Human-centered designed systems (Foyle, 2009)**: - Are intuitive and "natural" - Have readily accessible information - Support human capabilities (e.g., perceptual processing) - Mitigate human limitations (e.g., memory) - Have features supported by "human factors design principles trace" - Enable appropriate task usage strategies

Next Steps:

- STBO human-centered flight deck displays
- Operational issues: Datalink coordination between STM system and flight deck
  - Integration with SARDA (Spot and Runway Departure Advisor)



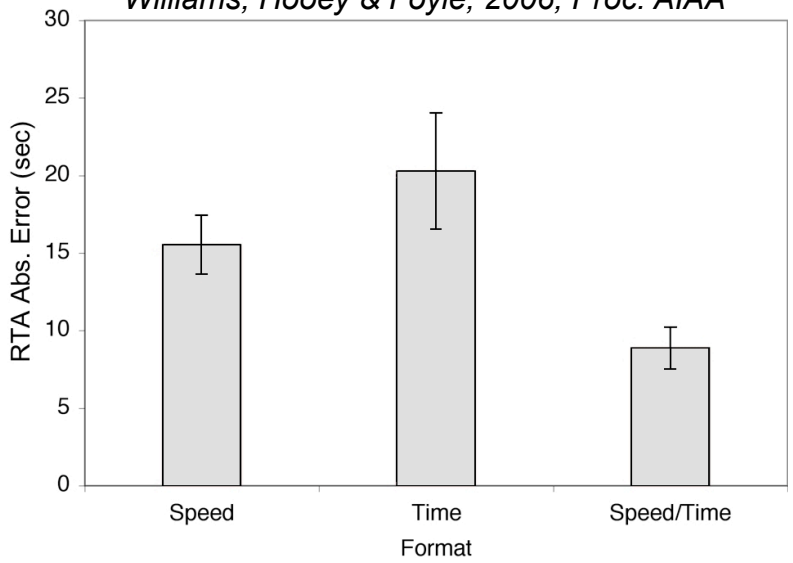
Backup Slides

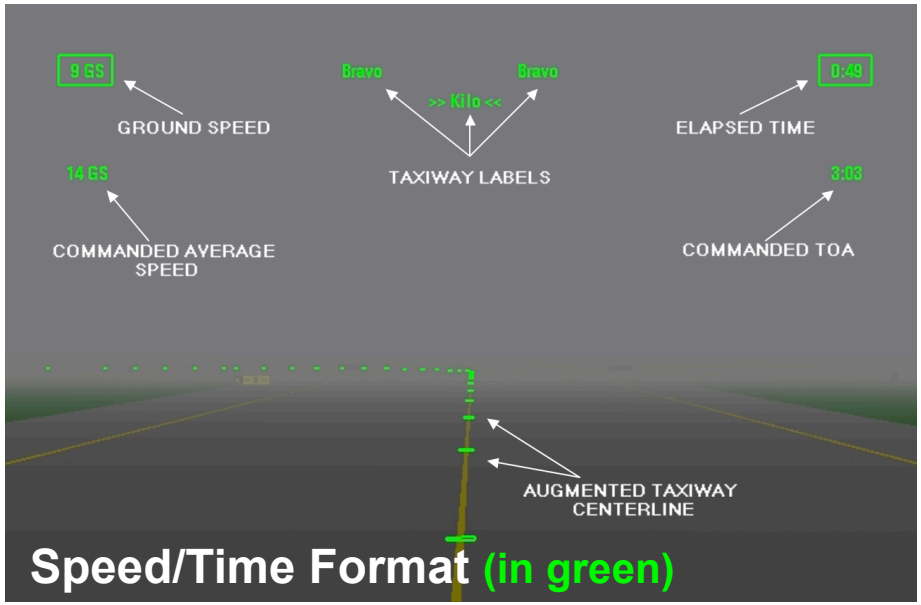
Preliminary Experiment: Pilot information requirements for STBO taxi clearances

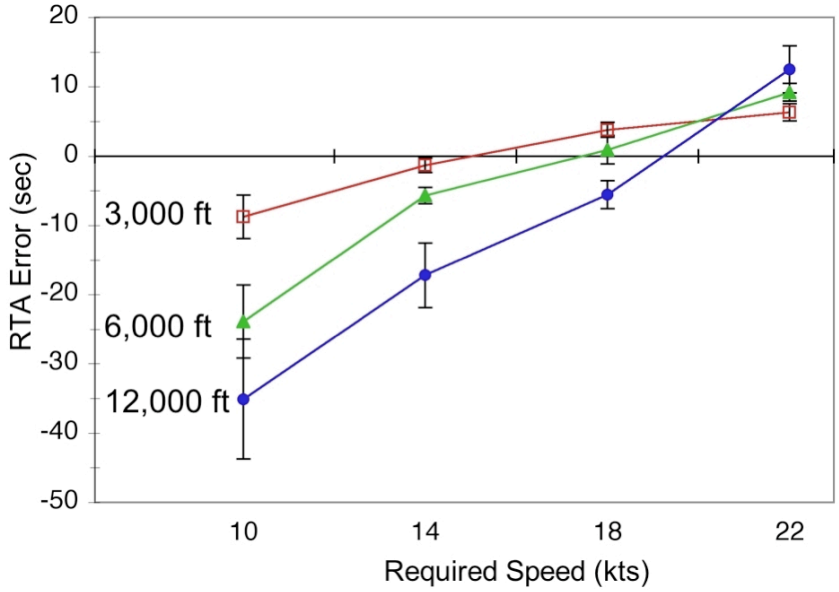
Objective: Initial Baseline 4-D Taxi Navigation Study

- 18 Current Captains
- Minimal display information (baseline study)
- STBO Taxi Clearance Formats
  - **Speed**: Commanded average route speed + Current speed
  - **Time**: Commanded time to RWY + Elapsed time
  - **Both**: All
- Results
  - Less RTA error with Both Time and Speed clearances
  - More RTA error with longer routes
  - Slower speeds → early arrival; Faster speeds → late arrival
  - Eyetracking usage - speed used early in route, then switch to using time information

Williams, Hooey & Foyle, 2006, Proc. AIAA







Preliminary Experiment: Pilot information requirements for STBO taxi clearances

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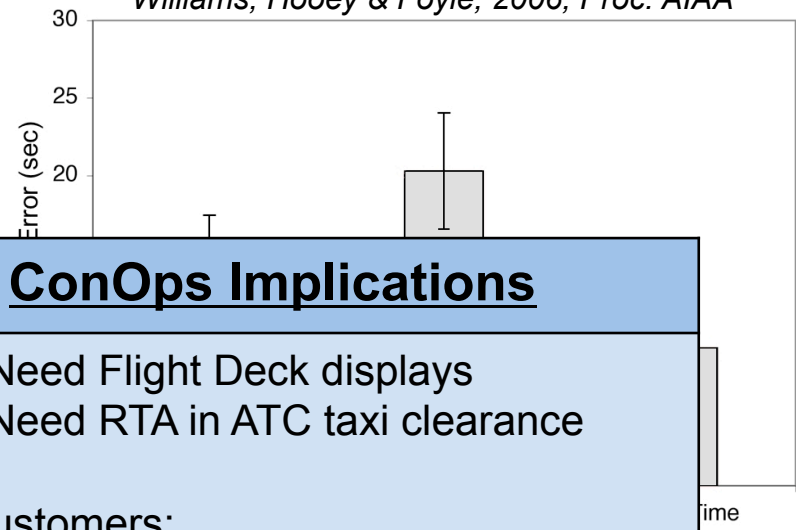


Findings

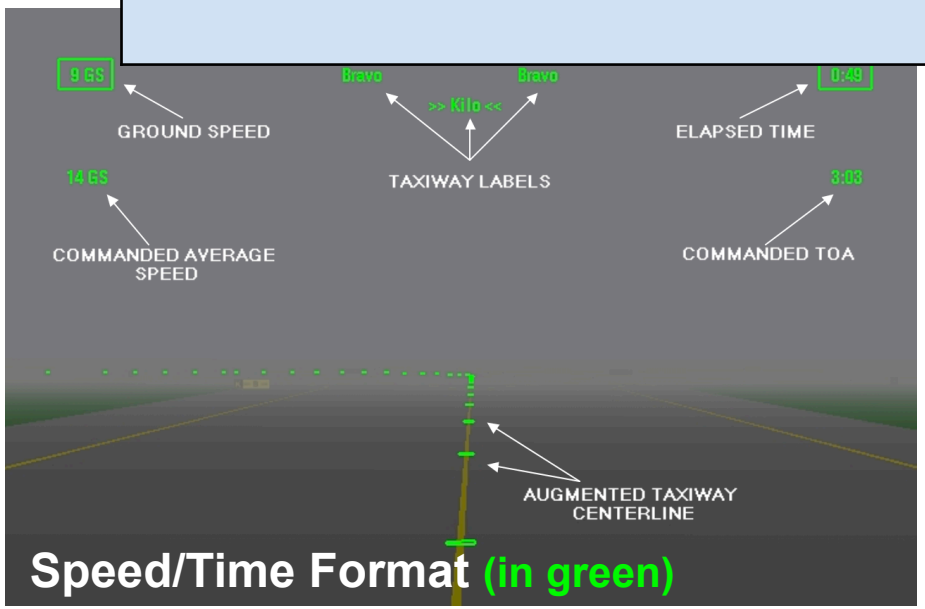
To accurately meet RTAs:

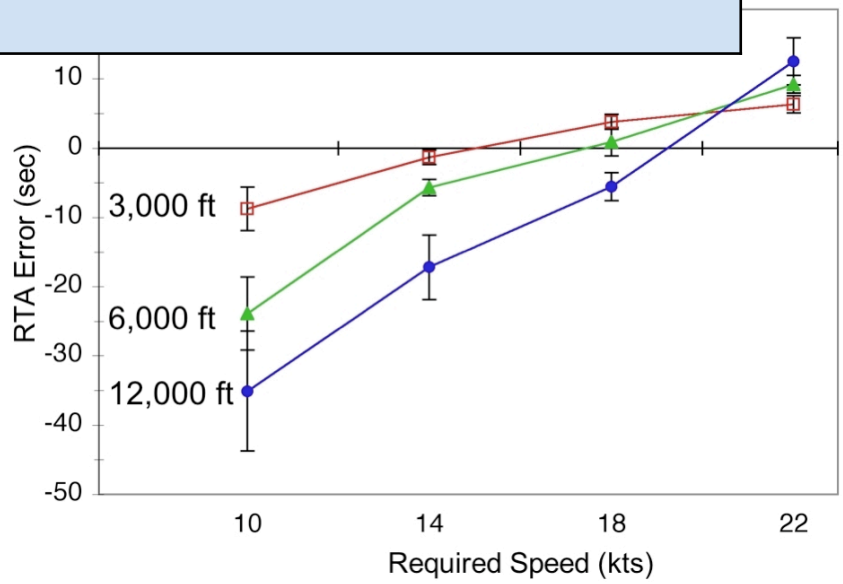
- Need both Speed (A/C control) and Time (RTA) information

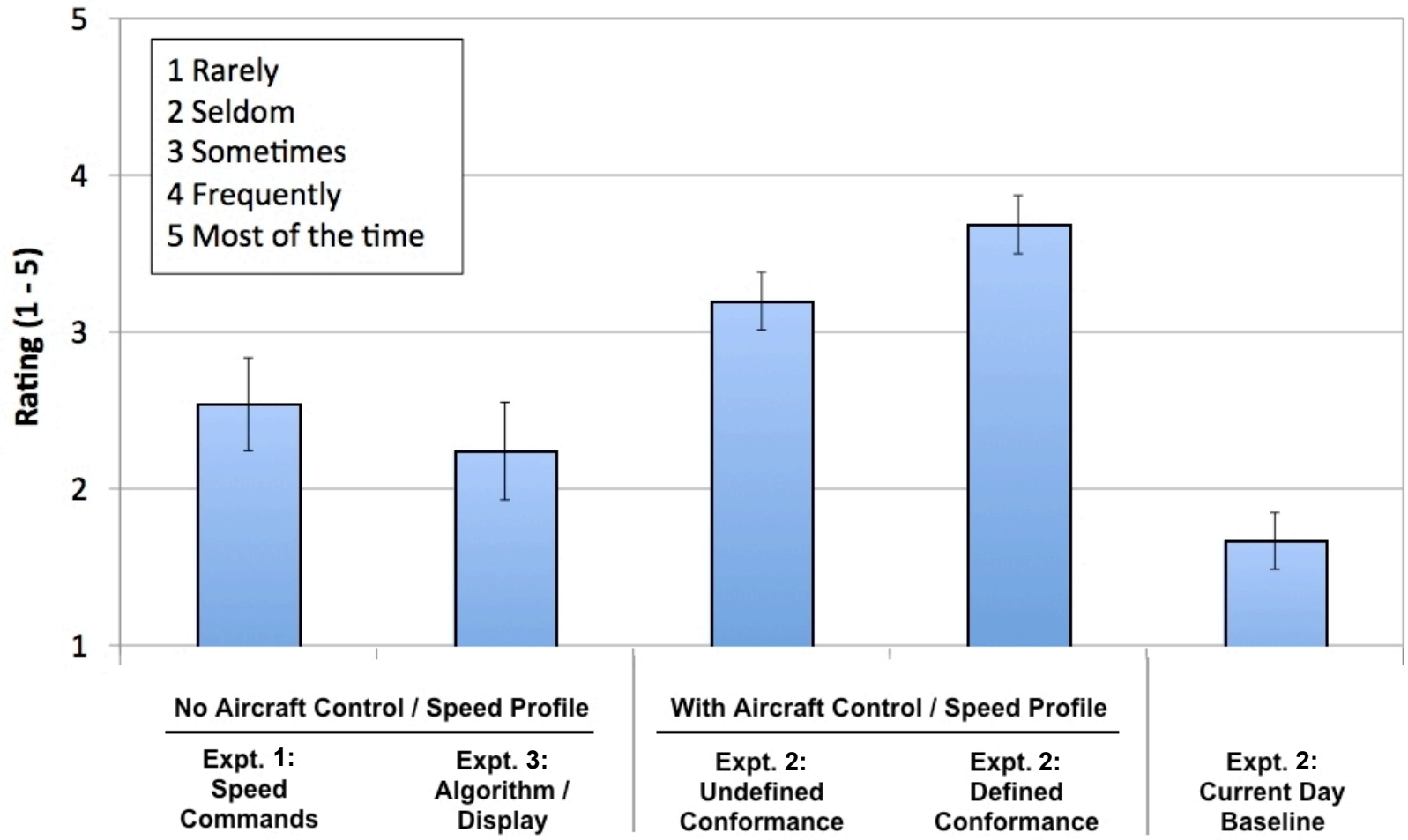
ConOps Implications

- Need Flight Deck displays
- Need RTA in ATC taxi clearance

Customers:
FAA, avionics/EFB mfg.





Cross-Studies: Usage/Safety Implications

"How often did you find yourself ***focusing on the PFD Speed or Time*** display, when you ***should have been paying attention to the external taxiway environment***?"